THE POLITICAL-ECONOMY OF SCIENCE AND (BIO) TECHNOLOGY: THE EMERGENCE OF AGRICULTURAL BIOTECHNOLOY IN CANADA

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Abstract

The development of genetically modified (GM) seeds has been followed by the rapid production of GM crops. Many insightful contributions have been made in the academic literature on the emergence of agricultural biotechnology, however, some gaps remain. First, there is a lack of emphasis on capitalist development in relation to agricultural biotechnology. Second, the capitalist character of the state is underemphasized. Third, there is little discussion about the interests underlying pro-GM crops discourses. Fourth, economic studies on GM crops rely on data and mathematical models to reach conclusions but do not explain them.

The problematic for this research is: how are capitalist social relations manifested in and supported by the development, adoption, and production of GM crops? The development of agricultural biotechnology is the result of capitalist social relations that demand innovation. This is enabled by a conjunction of social actors and scientific practices. The outcome is a research and development (R&D) structure that broadly accommodates capital by promoting the patenting of life forms in agriculture, concentration and centralization among multinational GM seed and agrochemical corporations, and the global production of GM crops.

In the Canadian case, an attempt is made by the state to secure the agricultural biotechnology industry through the procurement of R&D, legislation, and regulation and by the state countering civil society organizations that challenge such outcomes. In addition, the state and sections of civil society, government scientists and bureaucrats, corporations, and industry supported websites and NGOs play an important role in the construction of a pro-GM crops discourse that serves to control the discursive norms

and institutional contexts that surround agricultural biotechnology. This seeks to represent the interest of capitalist accumulation and those of individual capitals as the general interests of the Canadian public and farming communities. Lastly, the restructuring of the agricultural sector encompasses different conditions among which has been greater concentration and centralization of multinational GM seed and agrochemical corporations and the increase in the production of GM crops. The consequences for Canadian farmers include stagnant net farm income despite increasing yields and gross income, higher farm expenses and debt, and stringent patent laws.

Dedication

To Carol, Nicholas, and Gabrielle.

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Introduction

1.1 Introduction

From the time that human crop cultivation began, farming communities have attempted to improve the genetic makeup of plants. The histories and geographies of these endeavours have evolved over centuries. Initially, farming communities developed well-performing varieties through breeding. Breeding involves the selection of certain genetic variants from a few chosen plant species according to their suitability as edible or non-edible resources. Novel genetic variations in wild populations arise from a relatively slow process of naturally occurring mutation and the mixing of genomes that occurs with sexual reproduction (Thieman and Palladino, 2012).

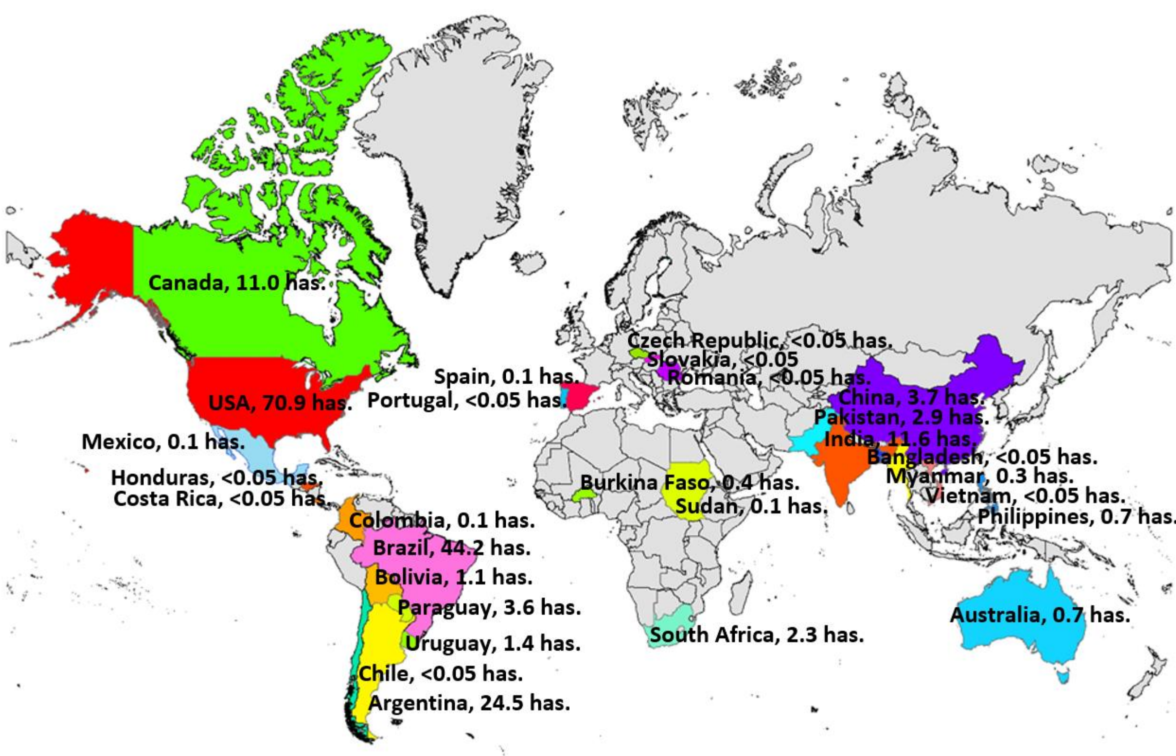
Over the past century, however, plant breeding has developed incrementally by harnessing advances in plant biology, supplemented at times by traditional empirical knowledge (lore), and informed by the principles of Mendelian genetics. Gregor Johann Mendel's early 20th century experiments with peas determined the way genetic traits are passed on to a plant's progeny. James Watson's and Francis Crick's work in the early 1950s on the structure of DNA set the stage for the conceptual advances that fostered the expansion of the biological sciences. In the 1960s, Marshal Nirenberg and Heinrich Matthaei determined that messenger ribonucleic acid transcribe genetic information from DNA by directing the assembly of amino acids into complex proteins. Paul Berg's successful experiments with the genetic modification (also referred to as genetic engineering, recombinant DNA technology or gene splicing) of molecules occurred in the early 1970s and initiated the modern field of biotechnology. Biotechnology refers to "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" (UN, 1992, 3). Herbert Boyer and Stanley Cohen advanced Berg's initial findings in significant ways by employing genetic engineering techniques to transfer genetic material into a bacterium allowing the imported material to be reproduced. These discoveries, among others, formed the basis for much of the R&D that followed in the field of agricultural biotechnology (Thieman and Palladino, 2012).

GM seeds were first created in the early 1980s by four groups of researchers working independently at Monsanto and Washington University in St. Louis, Missouri; University of Wisconsin in Madison, Wisconsin; and the University of Groningen in Ghent, Belgium (Werhane et al., 2004). GM crops are developed by a process of genetic engineering which allows individual genes from related or unrelated species to be inserted from one organism into another to enhance or supress specific traits. The most common GM crops have genes conferring resistance to insects (Lepidoptera, Coleoptera, nematodes), pathogens (viruses, bacteria, and fungi), herbicides (gluphosinate, glyphosate, phosphinotricin), abiotic stresses (frost, salt, heat, and drought), or improved quality traits (vitamin content, oil composition, protein quality, and altered growth and development). The key difference between a GM crop variety and an improved variety created by conventional plant breeding is that the genes are transferred without sexual crossing. In addition, with conventional breeding the specific genes controlling a trait cannot be identified, whereas with genetic engineering well-characterized genes are transferred in a targeted manner (FAO, 2005).

Throughout the 1980s, there was a surge of investment in the development of agricultural biotechnology, initially by start-up companies financed by venture capital followed by multinational corporations. Although many of the multinational corporations had no scientific expertise in either biotechnology or plant breeding, they recruited scientists and engineers and acquired seed companies with experience in plant breeding and the commercialization of seeds. For example, Monsanto is one of the largest agricultural biotechnology companies in the world. Founded in 1901, it initially produced saccharin (artificial sweetener), industrial chemicals, toxic chemicals (polychlorinated biphenyl), herbicide orange (Agent Orange) a defoliant used by the US military in the Vietnam War), and plastics (AstroTurf brand). Later, in the 1980s, it shifted its focus to agricultural biotechnology and began investing heavily in R&D and acquiring seed companies (Tokar, 1999). Also, in the 1980s and 1990s intellectual property (IP) laws in the form of patents began to enter plant breeding. IP laws have allowed the private seed industry to recoup investment through royalty collection and foster further research, organizational capability, and growth (Stein, 2005).

Massive investments in agricultural biotechnology R&D combined with newly emerging IP rights regimes have resulted in significant developments in the agricultural biotechnology industry. The first GM crop field trials were conducted in France and the US in 1986 using herb-resistant tobacco. By 1995, the two leading countries to conduct field trials were the US (1,952 field trials accounting for 54% of global) and Canada (486 field trials accounting for 13% of global). By the end of 1995, 35 applications or petitions were granted to commercially grow 9 GM crops, involving 8 traits in 6 countries and the EU, with most of the approvals in the US (20) and Canada (8) which together accounted for 80% of the number of approvals worldwide. Commercialization began in China in 1992 with a virus-resistant tobacco. In the US, the first GM crop was released in 1994, a tomato genetically engineered to delay rotting. In Canada, the first GM crops were released in 1996: herb-resistant canola, insect-resistant corn, and insect-resistant potato (James and Krattiger, 1996). By 1997, commercially grown GM crops reached 1.7 million hectares globally and continued rising to a record 179.7 million hectares (approximately 10% of global cropland) in 2015 of mostly maize, cotton, canola, and soybean, making GM crops the fastest adopted crop technology in the modern era (James, 2016) (see Map 1.1).

Map 1.1: Global Area in Millions of Hectares of GM Crops by Country



Note and source: special thanks to Asutosha Acharya for creating this map, (James, 2016).

Despite such adoption rates, however, the genetic modification of agriculture has resulted in dramatic conflicts. By the late 1990s, countries in Western Europe outright rejected the adoption of GM crops, and opposition emerged in many regions around the world: field trial crops were burned, experimental stations were attacked, and the global power of multinational corporations controlling GMOs was contested (Herring, 2007). Moreover, widespread disagreement continues among scientists, activists, regulators, and the general public about how to understand genetic modification in agriculture and what the possible positive or negative outcomes may be from the adoption of GM crops. Variously positioned social movement groups in diverse geographical locations have emphasized different concerns including the moral imperatives of 'playing god' or patenting life forms, the safety of foods derived from genetic modification, the ecological impacts of introducing novel plants into the environment, the loss of the ability of farmers to save seeds, 'biopiracy' through patent laws, and the control that multinational corporations are gaining over agriculture, science, and regulatory apparatuses (Eaton, 2013). Despite this extremely wide-ranging set of issues, public and academic debate tends to coalesce around either pro- or anti-GM crops discourses. Such controversies have given rise to a globally contentious politics and unprecedented policy dilemmas.

1.2 Gaps in the Academic Literature and Formulation of the Problematic

Given the complexity of these issues, various perspectives have been advanced in the academic literature that examine the development, adoption, and production of GM crops. In general, there are three overlapping and interrelated perspectives: developmental, political-economic, and civil society, that respectively bring into focus economic growth and improving welfare, the relations of production and exchange, and interventions by social groups. The academic literature that examines the development of agricultural biotechnology and the adoption and production of GM crops provides many insightful theoretical and empirical contributions that leading scholars have made, however, some gaps remain. First, there is a lack of emphasis on the development of capitalism as it relates to the agro-food system including agriculture and agricultural biotechnology. Second, the role of the state, in terms of its capitalist character, has been underemphasized. Third, there is little discussion about the interests underlying the construction of pro-GM crops discourses. Fourth, studies that examine the economic effects of the production of GM crops rely on data and mathematical models to reach conclusions but do not explain them. Given the gaps in the literature, the problematic for this research is: how are capitalist social relations manifested in and supported by the development, adoption, and production of GM crops?

1.3 Case Study: The Emergence of Agricultural Biotechnology in Canada

The history and geography of the development of agricultural biotechnology in Canada may be traced initially to the technological innovations in the canola sector. According to Phillips and Khachatourians (2001, 23), “Canola is a product of innovation. From the very beginning, the development of rapeseed into a new plant variety, the products of which were suited to human and animal feeding purposes, was a science-driven process”. Also, Gray et al. (2001, 90) asserted, “In Canada, canola is probably the most recent and pronounced example of how R&D can result in the rapid ascent of a crop to a multi-billion dollar status from humble origins”. The invention, innovation, and investment in the development of canola varieties initially occurred in Canada and has been a defining feature of the canola sector since the 1940s.

During the Second World War, Canada experienced shortages of oil imports (rapeseed oil and other oils) from Asia and Europe. Although rapeseed was cultivated in some Asian countries to produce vegetable oil for human consumption, it was not considered suitable for human consumption in Canada due to its high concentration of erucic acid. Instead, rapeseed oil was used in Canada for industrial purposes such as machine and engine lubricant. The geopolitical context of blocked oil imports during the Second World War led policy-makers to perceive Canada's dependence on foreign oil for both industrial and dietary purposes as a national weakness. Self-sufficiency in oil became a concern of the Canadian Defense Board and the modification of industrial rapeseed oil into edible oil emerged as a priority (Busch and Juska, 1997). It was soon discovered that rapeseed grew well in parts of Ontario and the prairies, and in 1943 the Forage Crop Division of the Canada Department of Agriculture imported 18,640 kilograms from the US and distributed it to Canadian farmers (Kneen, 1992). These events ultimately initiated the development of the rapeseed industry in Canada.

Following the Second World War, rapeseed was not established as an economically viable product by the private sector because there were no significant returns from its production to justify R&D investment and no legal protections of IP rights in plant breeding to protect innovation. These two factors left the rapeseed sector entirely in the control of the public sector where for the next two decades rapeseed research was conducted by Agricultural Canada, the National Research Council (NRC), a number of Canadian universities (e.g., University of Manitoba), and a few small

Canadian companies (e.g., Edible Oils, Saskatchewan Wheat Pool, and Canada Packers). As a result of this arrangement, research agendas were driven by government actions and priorities, and research findings moved around freely between all parties (McLeod, 1974).

In the 1950s, public sector scientists in Canada made important advancements in seed breeding. The first breakthrough occurred at the NRC Prairie Regional Laboratory which allowed the laborious testing of the oil composition of rapeseed to be reduced from a two-week process to a 15 minute period by using gas-liquid chromatography (GLC) analysis. The NRC assisted scientists at the Dominion Forage Lab of Agricultural Canada and the University of Manitoba with acquiring and using GLC analysis. GLC analysis was further refined by Keith Downey and a team of scientists at the Dominion Forage Lab by developing a technique of cutting a single seed in half to allow the remaining half to germinate and produce a new plant. Using GLC analysis and the half-seed method allowed scientists to test thousands of seeds in order to identify a seed for breeding with a low concentration of erucic acid (selective breeding). In 1963, one rapeseed was identified with no measurable quantities of erucic acid which was planted and yielded five whole seeds. These seeds ultimately formed the basis for the development of low-erucic rapeseed (Phillips and Khachatourians, 2001).

By the late 1960s, public sector R&D development of rapeseed oil reached a threshold. There was no single private or public institution with the means or incentive to invest in product development and market structures (e.g., extension and foreign market development). This prompted the federal government to inaugurate the Rapeseed Association of Canada (RAC) and the Rapeseed Utilization Assistance

Program (RUAP) to deal with market development and product research and extension. The RAC and RUAP were successful until the mid-1980s in mobilizing financial resources from industry and government to support R&D efforts. In addition, a significant development in this period were the efforts by rapeseed farmers to begin formulating separate provincial associations to mobilize producers to have a say in the development of the sector. Associations in the late 1960s were formulated in Saskatchewan and Manitoba, followed by Alberta in the 1970s, and Ontario in the 1980s. Although initially small with limited resources that came from membership fees, these associations began to focus on agronomy, policy development, and extension in order to accelerate the development of the sector (Gray et al., 2001).

With greater efforts and resources dedicated to R&D, the first low-erucic *Brassica rapa* variety was released in 1971, followed by the first low-erucic and low-glucosinolate *Brassica napus* in 1974, and the first double-zero (≤ 5% erucic acid of the total composition of the fatty acids and ≤ 3 mg glucosinolate) *Brassica rapa* in 1978. In order to effectively market the transformations that occurred to rapeseed, the RAC trademarked the name ‘canola’ (a contraction of **Can**adian **o**il and **l**ow **a**cid) in 1978 to differentiate the superior nutritional properties of its new product. In 1979, more than 3.4 million hectares of canola were cultivated globally. During the 1978-1979 crop year, Japanese imports of canola seed exceeded 1 million tonnes for the first time (CCC, 2014).

Heading into the 1980s, significant developments occurred inside the canola industry and outside of it. In 1980, the RAC formally completed its shift to canola when it changed its name to the Canola Council of Canada (CCC). While R&D efforts continued to improve the nutritional properties of canola, so that by 1986 the erucic acid content was decreased further to less than 2% of the total composition of the fatty acids and the glucosinolate to less than 30 μmol/g (Dupont et al., 1989), there was a shift in focus to R&D that would increase yields and extend the effective planting range. This was much more in line with improving production and the market for the product as stated in the by-laws of the CCC, "to explore potential markets and to conduct promotional and servicing activities of any kind conducive to the extension of markets throughout the world for the canola industry of Canada" (quoted in Gray et al., 2001, 94-95). Given these new priorities, private companies began to increase their contribution to the CCC's R&D efforts and the balance in the organization began to shift toward private companies, especially those associated with agricultural inputs and processing, which were beginning to be acquired by international players. The outcome was a tightly coordinated R&D program between the private industry, public institutions, and the CCC. By 1988, approximately 3.7 million hectares of canola were cultivated in western Canada and canola earned regulatory approval and market acceptance as a premium oil in all the major export markets (Gray et al., 2001).

In addition to the developments that were taking place in the canola industry, in the early 1980s the Government of Canada began to aggressively promote biotechnology R&D development as part of a strategy to foster economic growth in an era of competitive innovation in high-technology industries, economic recession, and lagging manufacturing industries. The Science Council of Canada advised the federal government of the need to achieve 'technological sovereignty', which placed greater emphasis on integrating technological innovation into modern industrial processes. This required economic restructuring based on expanded cooperation between the public and private sectors and specialization in a limited number of critical technologies (engineering, information and computer technology, and biotechnology) that would strengthen Canada's domestic technological innovation and capacity. The Ministry of State for Science and Technology (MOSST) published a policy document entitled *Biotechnology in Canada* which articulated the federal government's framework for promoting and developing biotechnology. Moreover, MOSST created the private sector Task Force on Biotechnology which recommended a ten-year development project designed to stimulate R&D and investment in the biotechnology industrial sector. Incentives to private industry included: government funding and tax relief; expansion of the scientific base; increase in international collaborations; and attention to the Canadian regulatory framework so as to not disadvantage Canada in relation to other international competitors (Task Force on Biotechnology, 1981).

The work of MOSST and the Task Force on Biotechnology resulted in the Government of Canada adopting the National Biotechnology Strategy (NBS) in 1983 which primarily focused on developing R&D capacity ($22 million dollars were allocated to develop the strategy and an additional $100 million to fund national research centres) and a favourable investment climate. In addition, the National Biotechnology Advisory Committee was established under the auspices of the NBS to advise the minister of industry on the industrial aspects of biotechnology. In 1988, MOSST published the first policy document entitled *Biotechnology Regulations: A User's Guide*. This document stipulated that the regulation of genetically engineered seeds and plant varieties would fall under the provisions of the *Seeds Act*, as administered by Agriculture Canada. In general, the policy document developed a framework to introduce biotechnology products into the market that minimize environmental and health risks and foster competitiveness (Peekhaus, 2013).

With greater emphasis throughout the 1980s on biotechnology R&D and products for fostering competitiveness, several developments occurred in the 1990s which further consolidated the biotechnology industry in Canada. The decision by the US Patents and Trademarks Office to grant patents for whole plants in 1985, and the introduction of canola hybrid technologies and the first hybrid variety in 1989, prompted the Government of Canada to pass the *Plant Breeders' Rights* (PBR) act in 1990 which provided "a form of intellectual property rights by which plant breeders can protect their new varieties in the same way an inventor protects a new invention with a patent" (CFIA, 2015a). IP rights are considered vital, not only as an instrument by which to spur domestic innovation, but also as a means to gain entrance into world markets of innovation by facilitating the transfer of knowledge from institutions of higher education to the private sector. The PBR strengthened private control over IP in the breeding and seed business. This has resulted in significantly greater use of contracts, often involving a web of relationships that link research units with seed companies, other input providers, farming communities, processors, and marketers. The private growth in breeding and seed business was increasingly encouraged by the federal and provincial governments. Public sector research agencies refocused their efforts to complement private sector interests (Gray et al., 2001).

In addition to the development of IP laws in the US and Canada, a concerted campaign based on aggressive corporate mergers and acquisitions as well as partnerships among the largest multinational corporations in agricultural biotechnology was taking place. In 1996, the top 11 seed companies (Monsanto, DuPont, Syngenta, Groupe Limagrain, Land O'Lakes, KWS SAAT SE, Dow, Sakata, DLF-Trifolium, Takii) accounted for 37% of the world's seed market. Moreover, within a short decade since its shift to agricultural biotechnology in the 1980s, Monsanto emerged as the largest player in the industry (Peekhaus, 2013). Following vigorous marketing in Canada of GM canola, soybean, and corn (the three largest GM crops cultivated in Canada), Monsanto received regulatory approval from Health Canada to market glyphosate tolerant canola for food use in 1994. Glyphosate tolerant canola was developed through a specific genetic modification of *Brassica napus* to be resistant to the activity of glyphosate herbicides (Health Canada, 1999), which brought together previous innovations in the development of rapeseed/canola with more recent innovations from Monsanto. Monsanto's glyphosate tolerant soybean received regulatory approval from Health Canada to market for food use in 1996. The glyphosate tolerant seeds, marketed as 'Roundup Ready', are genetically engineered to produce crops capable of surviving post-emergent applications of 'Roundup', a broad-spectrum non selective systemic herbicide that is sprayed and absorbed through the leaves of the plants (Health Canada, 2000). Monsanto's insect resistant corn received regulatory approval from Health Canada to market for food use in 1997. Insect resistant corn is genetically engineered to contain a gene derived from the naturally occurring soil bacterium *Bacillus thuringiensis* (crops containing this gene are commonly referred to with the prefix Bt, for example, Bt-corn). The bacterium produces a crystal protein that destroys the digestive tract of certain insects when ingested and mixed with stomach acids (Health Canada, 1997).

Given these developments in the agricultural biotechnology industry, by the mid-1990s the Government of Canada adopted a shift in science and technology policy that identified the need for mechanisms to improve the management of science and technology resources more strategically across the federal government's science departments and universities, further enhancing the R&D structure for the development of biotechnology. Underpinning this strategy were substantive federal investments made to enhance capacity building at universities and develop networks to integrate academic research with industry priorities to commercialize new inventions. Government mechanisms to improve public and private relationships and science investment efficiency resulted in the creation of the Canadian Foundation for Innovation and the Canadian Research Chairs at universities. This transformed model of science policy is anticipated not only to help leverage R&D resources from across the federal government's science departments, but to address national science priorities and take advantage of the basic science infrastructure in the university system. These institutional changes have resulted in the restructuring of the federal government's science departments to improve the governance of innovation policies and address economic, social, and environmental priorities. For example, Agriculture and Agri-food Canada (AAFC) has implemented the Agricultural Policy Framework to coordinate research and innovation efforts across provincial governments, industry, and public research institutions, and to maximize the return on science investments in priority research areas (Carew, 2005).

With the R&D structure and IP laws well established, the Canadian Biotechnology Strategy Task Force (CBS) was inaugurated in 1997 to review and further develop the NBS. The newly formed task force consulted with provincial officials, industry, non-government organizations (NGOs), scientists, academics, and other relevant stakeholders about the visions, goals, and principles of renewed national biotechnology strategy as well as its impact on biotechnology R&D. The formation of the CBS was followed by the establishment of the Canadian Biotechnology Advisory Committee (CBAC) in 1999. The CBAC identified five research areas: the regulation of GM foods; IP related issues in biotechnology; novel uses of biotechnology such as stem cells; the integration of ethical and social issues into biotechnology; and the consequences for privacy that emerges surrounding biotechnology (Government of Canada, 2004). According to Peekhaus (2013, 25), "Although the CBS and the CBAC documents articulate the importance of social and ethical dimensions in informing biotechnology policy development, the overall tone of both the federal biotechnology strategy and the various reports published by the CBAC leave the reader with the unmistakable conclusion that the commercialization of this science and its resulting technological applications is the driving motivation".

Heading into the 2000s, the Government of Canada had clearly positioned itself as a world leader in biotechnology R&D and commercialization. This has been substantiated by significant levels of public funding. For the fiscal years from 1997-1998 to 2008-2009, the federal government's biotechnology expenditures for R&D and related scientific activities was nearly $8 billion (Statistics Canada, 2001, 2005, 2010). In addition, Canada's Growing Forward strategic framework, which encompasses the policies and programs put in place to support the Canadian agriculture and agro-food sector, committed $1.3 billion for the fiscal years from 2009-2010 to 2012-2013 in order to “Accelerate the pace of innovation and facilitate the adoption of new technologies” (Miller, 2012, 2). Other public funding came from different sources: the Industrial Research Assistance Program invested $60 million between 1998 and 2006; Technology Partnerships Canada invested $293 million between 2001 and 2006; the Scientific Research and Experimental Development Tax Incentive Program provided over $3 billion in tax relief to Canadian businesses in 2006; and the Business Development Bank of Canada committed to $191 million for the fiscal years from 2006-2007 to 2009-2010 (Peekhaus, 2013, 2-3). More specific to agricultural biotechnology, the Canadian Crop Genomic Initiative, which is a major departmental biotechnology project aimed at identifying the structure and function of key crop genes, is helping to develop Canadian crops, specifically corn, soybean, canola, and wheat, to improve disease and insect resistance, cold and drought tolerance, and yield and quality attributes (Government of Canada, 2003).

Also in the 2000s, further consolidations were taking place among multinational seed corporations. In 2009, the top three seed companies in the world, Monsanto, DuPont, and Syngenta, accounted for 23%, 14%, and 8% respectively totaling 45% of the global proprietary seed market, and seed revenues of approximately US$7.3 billion, US$4.6 billion, and US$2.5 billion respectively totaling US$14.4 billion (Peekhaus, 2013, 44). In terms of Canadian companies, there has been a surge of small to medium size firms, from 358 in 1999 to 532 in 2005, an increase of nearly 50%. Medical biotechnology firms represented 58.3% of the total biotechnology firms, followed by

20.1% agricultural biotechnology firms, and 18.6% industrial biotechnology firms; however, 50% of biotechnology companies have less than 20 employees, and 80% have less than 100 employees and are located in Ontario, British Columbia, or Quebec. In 2005, 13,433 employees worked in biotechnology firms, up from 7,749 in 1999, an increase of 73.4%. Medical biotechnology firms accounted for 80.9% of the total biotechnology related employment, followed by 9.8% in agricultural biotechnology, and 8.6% in industrial biotechnology. Private biotechnology R&D expenditures increased at an average annual rate of 12.7% during the 1999-2005 period, from $831 million in 1999 to $1.7 billion in 2005. Medical biotechnology R&D represented 87.3% of the total biotechnology R&D in 2005, while agricultural biotechnology R&D and industrial biotechnology R&D accounted for 9.2% and 2.8% respectively. Nominal biotechnology revenues increased at an average annual rate of 13.7% during the 1999-2005 period, from $1.95 billion in 1999 to $4.20 billion in 2005. Medical biotechnology was responsible for 70.6% of total biotechnology revenues, followed by 24.6% from agricultural biotechnology and 4.3% from industrial biotechnology (de Avillez, 2011). Canada's biotechnology economy has reached nearly $78 billion per annum, or 6.4% of Canada's GDP (Pellerin and Wayne, 2008). Canada represents approximately 4% of the global biotechnology industry revenues, but only 1.8% of the global economy (World Bank, 2011). According to the Conference Board of Canada, biotechnology is a critical technology platform essential to Canada's ongoing prosperity (Conference Board of Canada, 2005).

Despite such remarkable developments in biotechnology in general and agricultural biotechnology in particular in the Canadian context, resistance has not abated. Among the many opponents of GM crops are three main groups in Canada that are involved in the resistance movement against agricultural biotechnology: Greenpeace Canada, Canadian Biotechnology Action Network (CBAN), and the Canadian National Farmers Union (NFU). In general, there are three interconnected issues that these groups address: health and environment, 'anti-globalization', and consumer/consumption. Greenpeace is a global organization based in Amsterdam, the Netherlands with offices in more than 40 countries. Greenpeace focuses on many different environmental issues including "Campaigning for sustainable agriculture by rejecting genetically engineered organisms, protecting biodiversity and encouraging socially responsible farming" (Greenpeace Canada, 2015a). In Canada, Greenpeace Canada has been a proponent of mandatory labeling of genetically engineered foods and took part in the coalition against GM wheat (Eaton, 2013). Greenpeace Canada is known for its work among civil society organizations with more than 90,000 supporters in Canada and 2.9 million members worldwide. Dissemination is done through door-to-door canvassing including signature collection on various issues, telephone calling, and extensive mailing and e-mailing of a monthly magazine to members (Greenpeace Canada, 2015a). Beyond the Canadian context, Greenpeace along with Friends of the Earth played an instrumental role in challenging the EU's relatively permissive and supportive biotechnology strategy resulting in a sea change between 1996 and 1999 which ended with the EU turning against the adoption of GM products (Tiberghien, 2007).

Another prominent group in Canada is the CBAN, which is composed of various environmental, social justice, and consumer groups. The stated mission reads, "To promote food sovereignty and democratic decision-making on science and technology issues in order to protect the integrity of the environment, health, food, and the livelihoods of people in Canada and around the world by facilitating, informing and organizing civil society action, researching, and providing information to government for policy development" (CBAN, 2015a). Although the CBAN was formed in 2006, informal collaborations prior involved campaigns which stopped the regulatory approval of Monsanto's bovine growth hormone for dairy cows and pressuring Monsanto into abandoning its plans to introduce GM wheat into the Canadian market. Part of the CBAN's resistance to biotechnology has included engaging with broader political-economic issues including the current phase of the neo-liberal form of capitalism in which biotechnology is being developed. The group has highlighted some of the deficiencies in Canada's regulatory system and the need for public involvement in parliamentary debates. One of the goals has been to democratize decision-making processes around genetic engineering. Dissemination is done through public lectures on a range of topics including: scientific, social, economic, and political issues from prominent speakers; film viewings (e.g., *The World According to Monsanto*); and cross-Canada speaking tours about the global impacts of biofuels on food, farmers, and human rights. One of the challenges that has been highlighted by the CBAN in the debate over GM technology is the importance of explaining a complex subject matter in a way that is accessible to a general audience. Accordingly, the CBAN has produced a number of publications on its website that not only raise issues but spur readers to take action.

The NFU is a direct-membership voluntary organization formed to unite provincial farmers' unions (excluding Quebec) around issues that focus on agricultural and social policies that preserve and promote family farming as a basic food production unit in Canada. The NFU has conducted a number of successful campaigns around GM wheat, GM seeds, and plant breeders' rights, among others. The NFU works in collaboration with other NGOs, environmentalists, and social justice activists interested in food and food policy issues (NFU, 2015). Dissemination is done through a monthly newsletter, social media, public meetings, membership discussions, cooperation with receptive parliamentarians and parties, and engagement in parliamentary committee meetings.

While resistance from opponents of GM crops has been pronounced, proponents have waged their own struggle. One of the most prominent organizations in this regard is the International Service for the Acquisition of Agri-biotech Applications (ISAAA). The ISAAA is a "not-for-profit international organization that shares the benefits of crop biotechnology to various stakeholders, particularly resource-poor farmers in developing countries, through knowledge sharing initiatives and the transfer and delivery of proprietary biotechnology applications" (ISAAA, 2015a). The organization has three centers: AfriCenter in Nairobi, Kenya; AmeriCenter, Ithaca, New York (hosted by Cornell University); and the SEAsiaCenter in Los Baños, Laguna, Philippines. The ISAAA has a multi-million dollar budget and receives funding from multinational corporations such as Monsanto, Syngenta, Bayer, and Pioneer as well as the UK's Biotechnology and Biological Sciences Research Council (a publicly funded body for research and training in the 'non-medical life sciences', and one of the seven Research Councils sponsored through the UK Government's Office of Science and Technology). The organization's high-profile board members, past and present, include: Robert Fraley, Executive Vice President and Chief Technology Officer at Monsanto and two-time (1998, 1999) recipient of the National Medal of Technology from then President Bill Clinton; Canadian inventor Wallace Beversdorf from the University of Guelph known for the OAC Bayfield soybean, which has been in commercial use for more than 20 years; Gabrielle Persley, Research Project Director at the Crawford Fund Australia, and advisor to the World Bank; and Ronald L. Phillips, awarded the Wolf Prize in Agriculture along with Michel A. J. Georges of the University of Liège for discoveries in genetics and genomics that laid the foundations for improvements in crop and livestock breeding, and important advances in plant and animal sciences (ISAAA, 2015b).

The ISAAA's chairman, Clive James, is the main author of the annual reports *Global Status of Commercialized Biotech/GM Crops*, which are commissioned by the GM crops industry and widely reported in the media. These reports provide comprehensive information and data on the global adoption patterns and production of GM crops. James has been influential in promoting the adoption of GM crops in several countries in the Global South, often meeting with heads of states and business leaders. GM crops are touted as part of the solution to alleviating poverty in the global South and benefiting small-scale resource-poor farmers. Support projects have been implemented that are geared towards "diversifying the biotech products in the market, in enhancing the public's awareness on the safe and responsible use of modern biotechnology, and in improving farm productivity and income through the sharing and exchange of knowledge and technologies" (ISAAA, 2015b) and technology transfer projects that facilitate “the transfer of proprietary technologies from the private sector in industrial countries for the benefit of subsistence farmers and the poor…[through]…exchange of technology, skills and experience between developing countries for their mutual benefit” (ISAAA, 2015b).

In addition, the ISAAA produces a wide variety of publications, videos, and an e-newsletter in several languages as part of their knowledge sharing initiative “on all aspects of crop biotechnology for all stakeholders, including consumers, farmers, policy makers, scientists, and the media” (ISAAA, 2015b) targeted at audiences of all ages, including children. Among the many publications have been extensive economic and environmental impact assessments of the global adoption of GM crops. These involve “estimating the economic, social, and environmental impacts of crop biotechnology. Impact studies usually employ scientific methods drawn from economics and the social sciences providing metrics of welfare effects of crop biotechnology adoption to include economic surplus, farm-level productivity and income, indices of health and nutrition, and indices of environmental footprints” (ISAAA, 2015b).

More specific to the Canadian context has been the national industry association BIOTECanada “with nearly 250 members located nationwide, reflecting the diverse nature of Canada’s health, industrial and agricultural biotechnology sectors” (BIOTECanada, 2015). The Industrial & Agricultural Committee is focused on the development of policy, advocacy, and investment that enable the biotechnology industry to penetrate traditional agricultural and industrial domestic and global markets with biotechnology products and seek solutions to environmental challenges. Specifically, the committee works on issues related to capital formation, regulatory environment, and market awareness and demand. The over 40 committee members represent leading organizations in industrial and agricultural biotechnology (BIOTECanada, 2015).

BIOTECanada has been directly involved in eliminating ‘zero-tolerance’ policies to ensure the continued adoption of agricultural biotechnology globally and to continue to have products of agricultural biotechnology bring value to the marketplace. BIOTECanada supports actions that facilitate the flow of goods in commerce and minimize trade disruptions. The National Biotech Accord aligns regional and national organizations leading the development of the Canadian bio-economy. Representing all facets of the technology, these organizations forge a national entity working to secure the long term sustainability for Canadian biotechnology-based companies and organizations (BIOTECanada, 2015).

1.4 Objectives and Researchable Questions

Based on the problematic for this research (how are capitalist social relations manifested in and supported by the development, adoption, and production of GM crops?), the theoretical foundation (political-economy of (bio) technology), and the substantive issues (the development, adoption, and production of GM crops in the Canadian context), four objectives and related researchable questions are defined.

Objective 1. To examine the historical and geographical development of agricultural biotechnology and the adoption and production of GM crops.

1.1 What role have public and private institutions played in the development of agricultural biotechnology?

1.2 How did changes in IP rights affect access to and use of genetic resources?

1.3 How has public and private investment in agricultural R&D affected the development of GM crops?

1.4 What are the effects of greater concentration and centralization among GM seed and agrochemical corporations?

1.5 To what extent have GM crops been adopted and produced globally?

Objective 2. To investigate the role of the state and civil society organizations in relation to the development, adoption, and production of GM crops at local and national scales.

2.1 In what ways has the federal government of Canada supported R&D and innovation?

2.2 What are the objectives of the Canadian biotechnology strategy and policies?

2.3 How have the federal government of Canada's biotechnology regulatory practices supported industry initiatives and addressed public concerns?

2.4 What effect have the federal government of Canada's biotechnology policies and regulatory practices had on the adoption and production of GM crops?

2.5. How does resistance by various civil society organizations affect the expansion of the market for biotechnology products?

2.6 Why do various government agencies continue to promote the development, adoption, and production of GM crops despite on-going public resistance?

Objective 3. To understand how discourses about biotechnology, GM crops, scientific progress, and economic development are employed to sustain and legitimate the use of GM crops.

3.1. How has the federal government of Canada and industry constructed and sustained a pro-GM crops discourse?

3.2. In what ways has the pro-GM crops discourse been narrowly conceived?

3.3. What are the purported benefits of GM crops for adopting countries in the Global North and South?

3.4 In what ways and how effective has been the dissemination of the pro-GM crops discourse?

Objective 4. To assess the economic implications of the production of GM crops for farmers.

4.1 To what extent has agricultural restructuring affected farmers in Canada?

4.2 Why has the federal government of Canada and the industry aggressively promoted the adoption and production of GM crops?

4.3 What effect has the adoption of GM seeds and associated technology use agreements had on farming practices?

4.4 Does the production of GM crops result in higher income for farmers?

4.5 How are the economic implications manifested over time, in terms of production, subsidies, and trade export?

1.5 Research Design and Methodology

The conceptual logic of enquiry in this research is based on a realist approach to abstraction, structure, and causation (see, for example, Bhaskar, 1975; Brown et al. 2001; Cox, 2013; Sayer, 1992, 2000). Following Bhaskar (1975), Sayer (1992) argued that knowledge must consciously devise methods for individuating objects, their attributes and relationships. Abstraction is the isolation in thought of a one-sided or partial aspect of a concrete object constituted by many aspects, elements, and forces. One must abstract from the many conditions and properties of an object to focus on those without which the object will not be what it is. The idea behind this is to take into consideration each concrete determination abstractly, in order to form concepts about them, before returning to the concrete with a rich array of theoretical understandings (Marx, 1993).

Objects are embedded in relations that are external or contingent and internal or necessary. Internally related objects or practices are structures. Social structures have positions associated with roles independent of the individuals occupying them. They are (re)produced together with associated resources, constraints, or rules, to determine events. Structures, however, may be invisible to common sense thinking.

The synchronic notion of abstraction allows only indirect reference to diachronic processes of change. The latter require causal analysis. The cause of something is what makes it happen, what produces or determines it. In the realist view, causality is not a relationship between discrete causes and effects; it is not about explaining patterns of events, but concerns instead the causal powers (or liabilities) of objects, their ways of acting, or mechanisms. The nature of an object and its causal powers are internally or necessarily related, but whether or not the powers are activated, and their effects when they are, depends on conditions whose configurations are external or contingent (Sayer, 1992).

In realism, the discovery of empirical regularities generates a series of questions into causal systems. For empirical regularities to be produced, the object possessing causal power must operate consistently ('intrinsic' condition for closure) and the relations between the causal mechanisms and external conditions must be constant ('extrinsic' condition for closure) resulting in a 'closed' system. Most systems, however, violate these conditions and are 'open' systems. The social sciences deal with such systems because humans interpret conditions, respond, and modify the configuration of a system. Whereas conventionally scientific laws are confirmed statements about empirical regularities, in the realist view laws refer to the necessary causal mechanisms and not to the contingent conditions in which mechanisms produce realities. Realist science attempts to make 'rational abstractions' which isolate significant elements having unity and autonomous force, as with structures. Theories in this view make their claims at the abstract level about internal relations, causal powers, and necessity in the world. By comparison, the form of contingent relations must always remain an empirical question, answered by observing actual cases (Sayer, 1992).

By drawing on a realist approach to abstraction, structure, and causation I address my problematic, objectives, and researchable questions using a combination of "extensive" and "intensive" concrete research designs (Sayer, 1992, 242-251, 2000). Extensive research primarily focuses on discovering common properties and general patterns as a whole. Extensive research uses descriptive and inferential statistics and numerical analysis. The focus is mainly on taxonomic groups that share similar formal attributes, but need not connect or interact with each other. The criteria by which samples are drawn are decided beforehand and adhered to in order to ensure representativeness. Testing in extensive research determines how general the particular findings are in the wider population (replication).

Intensive research primarily focuses on how structural or causal processes work out in a particular case or a limited number of cases. Intensive research uses mainly qualitative methods such as structural or causal analysis, participant observation, and/or interactive interviews. The focus is mainly on groups whose members may be either similar or different, but relate to each other structurally or causally. Identifiable individuals are of interest in terms of their properties and their mode of connection to others. Individuals may be selected one by one as the research proceeds. In this sense, intensive research is exploratory; as learning from one contact leads to others with whom s/he is linked, the causal group is built up. Testing in intensive research determines if the results apply to those individuals studied (corroboration).

According to Sayer (1992), intensive and extensive research designs may be employed in a complementary manner. Extensive research into empirical regularities, either in the form of correlations, trends over time, segregation or other indices of localization, can help give direction to more intensive forms of research. Having established some regularity or departures from it, intensive research helps to shed light on why that is the case. Much of this depends on the degree to which the quantitative analysis is informed by a careful conceptualization of the relations, including the structural or causal ones that are being evaluated. Care must be taken, therefore, when moving from regularity to an explanatory account.

The combination of extensive research for understanding macro-level dynamics combined with intensive research for understanding micro-level dynamics in this research provided me with a comprehensive understanding of the general patterns and causal processes at work in the development, adoption, and production of GM crops.

Quantitative analysis of secondary data at multiple scales helped me to understand the regularities, trends, and patterns of the development, adoption, and production of GM crops. Qualitative analysis of primary data helped me to understand the complex and multi-contextual relationships between individuals (e.g., farmers, government scientists, NGO activists) and institutions (e.g., farmers' union, corporations, government, NGOs) outside conventional categories and across multiple localities. Qualitative analysis brings out the specific contexts in which individuals find themselves (e.g., Canadian GM crops sector) and how such contexts causally determine complex outcomes (e.g., relations between individuals and institutions, capital flows and concentrations, technological development, economic effects on farmers) across multiple geographic spaces.

The qualitative research method that I chose was interviewing. Interviewing is a complex social interaction in which the researcher and respondent bring expectations to the interview. This requires a high level of interpersonal skills on the part of the researcher so that the respondent will feel at ease. A rapport must be established with the respondent so that a trusting relationship is developed. Interviewing is suited for describing both program processes and outcomes from the perspective of the target audience or key stakeholder. The goal of the interview is to deeply explore a respondent's point of view, feelings, and perspectives. This allows the researcher to have discussions with respondents that explain issues, complexities, and contradictions in order to produce rich and varied data (Kitchin and Tate, 2000; Valentine, 2005).

Semi-structured in-depth interviews are a less formal, less standardized, and more interactive method of interviewing that gives the researcher an effective manner of learning from the respondents what is significant in each of their circumstances. This enables the researcher to build upon and refer to knowledge gained about the specific characteristics of various respondents. A meaningful communication is established by adapting the questions and ideas in the interview to what is relevant to the respondents, and by being willing to discuss as well as to evoke answers. If the researcher's questions and emphasis is disputed by the respondents, this gives the researcher an opportunity to learn something about his or her own preconceptions or those of the respondents (Sayer, 1992).

Some caveats, however, should be noted with respect to interviewing. The epistemological premise of interviewing (i.e., that respondents are competent reporters of past and present events, experiences, attitudes, beliefs, behaviours, relationships, interactions, and so on) has been contested (Ackroyd and Hughes, 1992). Respondents are influenced in all sorts of ways that affect how they interpret and account for events and experiences to a probing researcher. Respondents may have cultural or strategic reasons for presenting information about themselves and others in a particular light and may leave out or distort some information (Weiss, 1994).

The process of reflecting on who I am and how my identity will shape the interactions that I have with contacts and respondents while in the field has been described as recognizing one's positionality and being reflexive. According to Kim England, reflexivity is a "self-critical sympathetic introspection and self-conscious analytical scrutiny of the self as a researcher" (England, 1994, 82). The task here is to think about how my social class, gender, race, nationality, theoretical orientation, politics, history, experiences, and so on, shape my research and interpretation of data (Schoenberger, 1992).

Several events have been instrumental in shaping who I am. I began to develop my geographical imagination by taking courses at York University's Department of Geography. These courses introduced me to many influential geographers that broadened my understanding of the significance of place, space, landscape, and nature. I met professors who were passionate about their work, exhibiting high standards in scholarship, yet expressed a genuine interest in students and encouraged an 'open door policy' in terms of their availability and willingness to speak to students. One of the professors that I connected with was Raju J. Das. Raju introduced me to the Marxist perspective in geographic thought. The Marxist approach appealed to me intellectually and became the theoretical approach that I would adopt in my academic work in general and my current research specifically.

For many years I have been involved in various community service opportunities that raised my political awareness. I volunteered for two years in the Yonge Street Mission Evergreen program (drop-in for street youth); I volunteered for one year in the Out of the Cold program (provides safe refuge, hospitality, and emergency shelter for homeless); I developed and volunteered for eight years in the Youth Drop-In Centre (the program provides support for at-risk youth). Currently, I am the vice-president of the Students for Social Equality at York University group (a political group that raises awareness about contemporary social, economic, and political issues); and the Critical Geography Reading Group in York University's Geography Department. These experiences have been instrumental in shaping my social, economic, and political perspective while interacting with respondents including: farmers, government scientists and bureaucrats, other academics, and activists.

I strived to understand the positions of my respondents in relation to myself as a researcher. I paid special attention to how respondents present their opinions and practices to me as a researcher who is situated differently from others with whom they interact on a daily basis. I took the position that not all explanations are equally compelling and that as a researcher I have a duty to differentiate among them. When I heard a similar explanation from a wide variety of respondents while conducting interviews (corroboration), I knew that that explanation was likely to have relevance. I strived to present the most coherent interpretations possible by taking multiple sources into account and considering the varied perspectives of my respondents. I employed an iterative process, moving back and forth between interview data, quantitative data, and established academic and non-academic (e.g., press releases, policy statements, farm newspaper articles) literature in order to develop a coherent account while keeping in mind the context under which different data were produced. I reflected on who I am and how my identity shaped the interactions I had with respondents. Through this process, I became more aware of the different power relations that exist between myself as a researcher and the respondents I interviewed and how such differences affect our interactions and the data produced by all parties.

I employed a sampling method referred to as “snowballing” (Valentine, 2005, 117), where a researcher relies on one or more contact(s) to recruit respondents. As this process gains momentum, the researcher builds up a sample of respondents. There are three reasons I chose this sampling method: first, given the controversial aspect of this research and the highly charged public opinions for and against GM crops, recruiting willing respondents was especially challenging. Initially, I relied on contacts (e.g., other researchers, academics) to refer me to potential respondents. This allowed me to begin identifying respondents that were engaged in different kinds of activities related to GM crops (e.g., farmers using GM crops, farmer union representatives). Second, this sampling method allowed me to establish trust and rapport with contacts and respondents by mentioning the name(s) of previous contacts and respondents. This facilitated the process of building a network of contacts and respondents. Third, this sampling method is exploratory and less stringent, allowing the researcher to make adjustments according to situational demands. For example, my initial contacts were researchers and academics, which led to contacts with farmers, followed by farmer union representatives, and so on. As the research progressed, the network of contacts and the number of respondents grew. This process was not planned; rather, it emerged out of situational demands that I faced in the field.

Snowballing sampling method and intensive research design raise issues regarding representativeness. Some authors argued that snowballing sampling method lacks the statistical accuracy and precision that underlies a probability based sampling design (Singleton and Strait, 1999). Accordingly, careful consideration should be taken to make the selected sample as representative as it can be of the population. One way that I addressed this issue was by examining documents on GM crops from different sources (e.g., academics, Government of Canada, NGOs, Statistics Canada), to determine the most effective method of selecting geographical areas (e.g., cities, provinces) and significant groups (e.g., farmer groups, NGOs, corporations, government institutions) that are relevant to the research. Moreover, according to Sayer (1992, 249), "intensive research fails to produce 'objective' results because its result are not representative (i.e. not replicable elsewhere). But providing there is no pretence that the whole population is 'represented', there is no reason why an intensive study should be less 'objective' (i.e. uncorroborated) about its particular subject matter than an extensive study". At the concrete level, the findings of this research may be unique and in this sense not 'representative'; however, in so far as intensive methods identify structures into which individuals are inserted and their mechanisms, the abstract knowledge of these may be more generally applicable. The findings provide an explanation about how the context in which the development, adoption, and production of GM crops is structured, and how the key agents under study fit into it, interact with it, and constitute it.

1.6 Secondary Data and Interviewing

Extensive research at the international and national scales provided me with an understanding of the indicators and processes behind the development, adoption, and production of GM crops globally and in relation to Canada. This allowed me to estimate the explanatory causality between factors and the variation among selected indicators on the perceived outcomes of the GM crops sector at a macro level. I analyzed secondary data from several international and national sources including: the World Bank; the Consultative Group for International Agricultural Research (CGIAR); the Food and Agriculture Organization of the United Nations (FAO); the ISAAA; the International Assessment of Agricultural Knowledge, Science and Technology for Development

(IAASTD); the International Food Policy Research Institute (IFPRI); Statistics Canada; Health Canada; AAFC; and the Canadian Food Inspection Agency (CFIA).

While every effort was made to access statistical data on GM crops from a variety of sources, this has been challenging. Global data on the adoption and production of GM crops, including country specific information such as the number of farmers cultivating GM crops, crop type, number of hectares, and so on, has largely come from one source, the ISAAA, with little to no comprehensive data from any other sources. The data from the ISAAA reports is used by international and national organizations such as the FAO, the CGIAR, the Organisation for Economic Co-operation and Development (OECD), the Government of Canada, among others. According to Peekhaus (2013), the accuracy of the ISAAA data has been questioned by NGOs and academics. For example, LobbyWatch claimed that in the 1998 *Global Status of Commercialized Biotech/GM Crops* "a figure of 12% was given by American farmers for GM soy yield improvements. However, a review of the results of over 8,200 university-based controlled varietal trials in 1998 showed an almost 7% average yield reduction in the case of the GM soy" (LobbyWatch, 2015). In the Canadian case, Peekhaus (2013) claimed that the 2011 *Global Status of Commercialized Biotech/GM Crops* reported that 10.4 million hectares of land were planted with GM crops, but according to Statistics Canada data approximately 9.2 million hectares of GM crops were planted in 2011.

Moreover, tracking data on GM crops in Canada from a variety of sources has been challenging. I contacted AAFC, the CFIA, and Statistics Canada and discovered that comprehensive disaggregate data according to conventional and GM crops are not available. Canadian agricultural statistics, for the most part, do not differentiate between conventional and GM crops and in cases where this is done the information is not comprehensive. For example, although GM corn and GM soybean have been cultivated since 1996 and 1997 respectively, initially in Ontario and Quebec and later in Manitoba, Statistics Canada began disaggregating statistics according to conventional and GM crops in 2006 for corn and soybean in Ontario and Quebec, but not in Manitoba. In the case of GM canola, the only comprehensive data comes from the CCC, while data on GM sugar beet is very limited (Peekhaus, 2013).

The extensive research provided me with insights about the empirical regularities of the adoption and production of GM crops and gave me direction for the intensive research. I familiarized myself with the issues surrounding GM crops in the Canadian context by reading academic literature, newspaper articles, information on pro- and anti-GMO websites, and watching YouTube videos and films. It became increasingly clear that there was a pronounced divide between opponents and proponents of GM crops. This is demonstrated by the plethora of information available for and against GM crops inside academia and outside of it, with very few people towing a moderate line. Also, I attended some anti-GMO rallies and met activists who tried to convince me of their positions of opposition. These rallies awakened me to how passionate people are about issues surrounding food, given that genetic modification in other areas such as pharmaceuticals has received less attention and has been less controversial.

Particular care and attention to ethical issues was taken into consideration in this research. An ethical review was conducted through York University and approval was granted to conduct interviews from 14 November 2014 to 14 November 2015. Also, the ethical review included the approval of an Informed Consent Form (see Appendix A) which stated the purpose of the research, the intended uses of the findings, and the legal rights of the respondents. This form was provided to all respondents prior to conducting interviews. The intensive research included 39 semi-structured in-depth interviews that were conducted between January and August 2015. During the interviewing process, I followed a sample of interview questions (see Appendix B) which were formulated prior to going into the field and developed significantly as the fieldwork proceeded and as I gained more information and insights into particular issues from the respondents.

I began by interviewing farmers that were cultivating GM crops and farm union members. While interviewing farmers, it became clear that there was a divide inside farming communities between adopters and non-adopters of GM crops. In some cases, those who adopted GM crops were viewed as 'selling out' and as threatening the livelihood of conventional farmers. Non-adopters were viewed as 'behind the times' and holding on to some nostalgic ideas about farming. All the farmers that I interviewed were very passionate about their work and the economic viability of farming in increasingly competitive markets.

Based on the insights that I gained from these interviews I began to identify a number of potential respondents from a variety of state and civil society organizations. This lead to expanding the field of research to include interviews with government employees, scientists, and anti-GMO activists. This stage of the interviewing process gave me a first-hand experience of just how controversial issues surrounding GM crops had become in the Canadian context. When I attempted to arrange interviews with

Government of Canada employees and scientists most of my telephone and e-mail communications were not responded to. In cases where I did get a response, I was often told by employees and scientists that they were not willing to provide any comments about GM crops. In some cases where I did secure an interview, respondents were required to receive approval from their supervisors prior to giving an interview. This often meant scrutinizing the Informed Consent Form, during which I felt I was the one being interviewed. In other cases, respondents did not want to sign the Informed Consent Form or allow me to record the interview. It became clear to me throughout these interviews that no one in the Government of Canada was willing to be critical of biotechnology agendas.

The interviews with farmers and the state and civil society actors in addition to newspaper articles, information on GMO websites, and watching YouTube videos and films allowed me to begin understanding the ways biotechnology and biotechnological information are constructed and how the state and industry have been complicit in sustaining the discourses that make a given technology acceptable. The whirlwind of information that members of the public on all sides of this debates face is simply astonishing. The information comes from different sources including: scientists, government employees, media personnel, multinational corporations, commercial leaders, and so on. On the one hand, GM crops are compared to the greatest of human achievements, on the other hand, they are viewed as part and parcel of the coming demise of humanity. These factors are indicative of the plethora of social, cultural, political, economic, and environmental implications as certain renditions about GM crops and their attending values are evaluated over others.

1.7 Data Organization and Analytical Procedures

The interviews that were recorded were transcribed. The transcribed notes and the handwritten notes from all the interviews were analysed using a general operational framework that was created to correspond with the objectives and researchable questions of this research. A thorough analysis of the primary qualitative data that was collected is provided in the following chapters. The secondary quantitative data collected from published sources were tabulated and organized around themes related to the substantive issues of this research using maps, tables, and figures. The results of this research will contribute towards an understanding of the causal dynamics and mechanisms associated with the development, adoption, and production of GM crops and the specific outcomes for farmers in particular and Canadian agriculture in general. The critical analysis presented in these chapters will contribute to the academic literature in three areas: the political-economy of (bio) technology, the GM crops industry in Canada, and economic geography.

1.8 Chapter Outlines

The dissertation is organized in the following way. In the second chapter (**The Political-Economy of Science and (Bio) Technology**) I present a theoretical framework for understanding the concrete historical and geographical development of science and (bio) technology. In section **2.2 From Agricultural Geography to Agricultural Biotechnology** I examine the relevant academic literature from agricultural geography (section ***2.2.1 Agricultural Geography***) which provides the general background of the theoretical debates and concrete understandings out of which much of the agricultural biotechnology literature has emerged (section ***2.2.2 Agricultural Biotechnology***). Having reviewed the literature, I identify some gaps (section ***2.2.3 Gaps in the Academic Literature***). Given the gaps in the literature, I present an alternative theoretical framework for understanding the development of science and (bio) technology (section **2.3 An Alternative Theoretical Framework for Understanding the Development of Science and (Bio) Technology**). I engage some of the debates concerning the contradiction between the social relations of production and the productive forces (section ***2.3.1 The Social Relations of Production and the Productive Forces***); the competition that impels capitalism towards perpetual revolutions in the productive forces (section ***2.3.2 Competition and Technical Change***); the dynamics of historical periods in the uneven development of capitalism that incorporate revolutions in technology (section ***2.3.3 Cycles and Technical Change***); and the geographically uneven character of technical change (section ***2.3.4 Geography and Technical Change***). These contributions provide the basis for an understanding of the development of agricultural biotechnology and the adoption and production of GM crops (section **2.4 The Development, Adoption, and Production of GM Crops**). In the Canadian context, I examine the role of the state and civil society (section ***2.4.1 The State and Civil Society***); the construction of a pro-GM crops discourse (section ***2.4.2 Agricultural Biotechnology Discourse***); and the economic implications of the production of GM crops for farmers (section ***2.4.3 Economic Effects of GM Crops Production on Farmers***). In section **2.5 Conclusion** I summarize the elements comprising the alternative theoretical framework.

In the third chapter (**Historical and Geographical Macro-Empirical Analysis of Agricultural Biotechnology**) I present a macro-empirical analysis of the development of agricultural biotechnology and the adoption and production of GM crops. In section **3.2 The Emergence of Agricultural Biotechnology** I examine the shift from public to private ownership of germplasm (section ***3.2.1 From Public to Private Ownership of Germplasm***); the ensuing IP rights in plant genetic resources (section ***3.2.2 Intellectual Property Rights in Plant Genetic Resources***); the investments in agricultural R&D (section ***3.2.3 Agricultural Research and Development Investment***); and the increasing concentration and centralization of GM seed and agrochemical corporations (section ***3.2.4 Concentration and Centralization in the Agricultural Biotechnology Industry***). In section **3.3 The Global Adoption of GM Crops** I explore the number of GM crops field trials conducted (section ***3.3.1 GM Crop Field Trials***); the adoption of GM crops by country and crop (section ***3.3.2 GM Crops by Country and Crop***); the economic impacts of adopting GM crops (section ***3.3.3 Economic Impacts of Adopting GM Crops***); and the specific cases of the US and Canada (section ***3.3.4 US Leads and Canada Follows***). In section **3.4 Conclusion** I provide a summary of the findings and draw out some conceptual implications and the contribution of the chapter to the academic literature.

In the fourth chapter (**The State, Civil Society, and the Canadian Agricultural Biotechnology Industry**) I examine the role of the state and civil society organizations in relation to the development, adoption, and production of GM crops. I bring into focus Canada's biotechnology R&D initiatives (section **4.2 Canadian Research and Development and Innovation**), strategy, policy (section ***4.2.1 Canadian***

Biotechnology Strategy and Policy), and regulatory framework (section ***4.2.2 Canadian Agricultural Biotechnology Regulation***), and their economic impact on the biotechnology industry (section **4.3 Market Impact of the Canadian Agricultural Biotechnology Industry**). Moreover, I highlight some of the rising contestations from civil society organizations (section **4.4 Rising Contestations**). In the conclusion (section **4.5 Conclusion**) I provide a summary of the findings, draw out some conceptual implications, and situate the contribution of the chapter in the broader academic literature.

In the fifth chapter (**Science, Technology, and Agricultural Biotechnology Discourse**) I examine how discourses about biotechnology, GM crops, scientific progress, and economic development are employed to sustain and legitimate the development of agricultural biotechnology. In section **5.2 Constructing a Pro-GM Crops Discourse** I examine the ways 'sound science', the 'authority' of scientists (section ***5.2.1 'Sound Science' and the 'Authority' of Scientists***), and the appeal to science (section ***5.2.2 An Appeal to Science***) are employed to sustain and legitimate the adoption and production of GM crops. In section **5.3 Disseminating the Pro-GM Crops Discourse** I scrutinize the various methods through which the pro-GM crops discourse is disseminated. In section **5.4 Conclusion** I provide a summary of the findings, draw out some conceptual implications, and situate the contribution of the chapter in the broader academic literature.

In the sixth chapter (**Economic Implications of the Production of GM Crops for Farmers**) I assess the economic implications of the production of GM crops for Canadian farmers. In section **6.2 Agricultural Restructuring in Canada** I provide an overview of agricultural restructuring and the effects on Canadian farmers (section ***6.2.1 Effects of Agricultural Restructuring on Canadian Farmers***). In section **6.3 Biotech Farming in Canada** I examine the R&D investment in agricultural biotechnology, the impact of multinational agribusiness corporations; the introduction of GM canola, GM corn, and GM soybean into Canadian agriculture; and the implications for farmers. In section **6.4 Farm Level Economic Impact of GM Crops Production** I examine the effects of GM seed contractual agreements on farmers (section ***6.4.1 Commercial Seeds and Technology Use Agreements***), the claims regarding GM crops and higher yields (section ***6.4.2 GM Crops and Yields***), and the impact on farm level income (section ***6.4.3 GM Crops and Farm Level Income***). In section **6.5 Conclusion** I draw out some conceptual implications and the contribution of the chapter to the academic literature. In the seventh chapter (**Conclusion**) I provide a summary of the research findings (section **7.2 Research Findings**), outline the contribution of the dissertation to the academic literature (section **7.3 Contribution to the Academic Literature**), and briefly chart an agenda for further research (section **7.4 Further Research**).

Chapter Two

The Political-Economy of Science and (Bio) Technology

2.1 Introduction

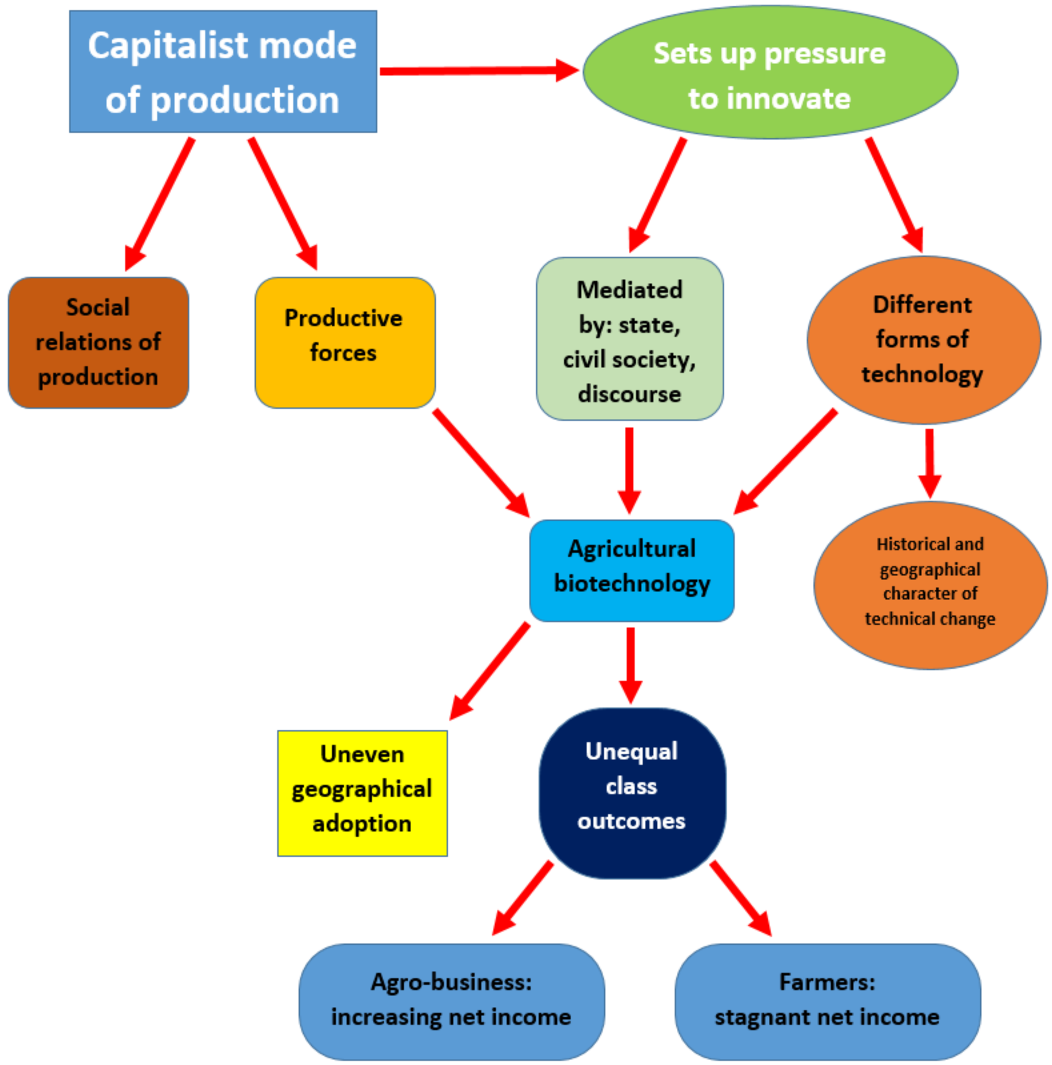
Prior to the rise of capitalism in Europe, the body of scientific knowledge in the West was that of the ancient Greeks as preserved by Arab scholarship in medieval monasteries. It was this body of knowledge during the era of scientific advance in the sixteenth and seventeenth centuries which supplied some of the conditions for the Industrial Revolution, but the connection was indirect, general, and diffuse, not only because science was not yet structured by capitalism and dominated by capitalist institutions, but also because technique developed in advance of, and as a prerequisite for, science. Science did not systematically lead the way for industry, but often lagged behind and grew out of industrial developments. Instead of formulating new techniques, science in its beginnings under capitalism more often formulated its generalizations in accordance with, or as a result of, technological development (Braverman, 1988, 107-116).

This may be contrasted with the manner in which science has been employed at the cutting edge of industrial change in the 21st century. Today, the social basis for large numbers of scientists in the colleges and universities, industries, and governments has been firmly established ushering in an era of unprecedented scientific and technological developments. The planned progress of technology has been accomplished by means of the transformation of science into a commodity bought and sold like other implements of production. Science and technological developments cannot be understood simply in terms of specific innovations, but must be understood in relation to a totalizing mode of production into which such developments have been integrated as part of ordinary functioning (Loeppky, 2005).

The purpose of this chapter is to present a theoretical framework informed by a Marxist political-economy approach for understanding the concrete historical and geographical development of science and (bio) technology. I specify the theoretical foundation and justification for my research project by situating the development of agricultural biotechnology and the adoption and production of GM crops in the progression of capitalism globally and in the Canadian context. Accordingly, I further our understanding of the critical role of science and (bio) technology in capitalist economy.

The chapter is organized in the following way. In section **2.2 From Agricultural Geography to Agricultural Biotechnology** I examine the relevant academic literature from agricultural geography (section ***2.2.1 Agricultural Geography***) which provides the general background of the theoretical debates and concrete understandings out of which much of the agricultural biotechnology literature has emerged (section ***2.2.2 Agricultural Biotechnology***). Having reviewed the literature, I identify some gaps (section ***2.2.3 Gaps in the Academic Literature***). Given the gaps in the literature, I present an alternative theoretical framework for understanding the development of science and (bio) technology (section **2.3 An Alternative Theoretical Framework for Understanding the Development of Science and (Bio) Technology**) which may be illustrated in the following way (see Figure 2.1).

Figure 2.1: An Alternative Theoretical Framework for Understanding the Development of Science and (Bio) Technology



I engage some of the debates concerning the contradiction between the social relations of production and the productive forces (section ***2.3.1 The Social Relations of Production and the Productive Forces***); the competition that impels capitalism towards perpetual revolutions in the productive forces (section ***2.3.2 Competition and Technical Change***); the dynamics of historical periods in the uneven development of capitalism that incorporate revolutions in technology (section ***2.3.3 Cycles and***

Technical Change); and the geographically uneven character of technical change (section ***2.3.4 Geography and Technical Change***). These contributions provide the basis for an understanding of the development of agricultural biotechnology and the adoption and production of GM crops (section **2.4 The Development, Adoption, and Production of GM Crops**). In the Canadian context, I examine the role of the state and civil society (section ***2.4.1 The State and Civil Society***); the construction of a pro-GM crops discourse (section ***2.4.2 Agricultural Biotechnology Discourse***); and the economic implications of the production of GM crops for farmers (section ***2.4.3 Economic Effects of GM Crops Production on Farmers***). In section **2.5 Conclusion** I summarize the elements comprising the alternative theoretical framework.

2.2 From Agricultural Geography to Agricultural Biotechnology

2.2.1 Agricultural Geography

The introduction of political-economy approaches to the study of agricultural placed emphasis on the social relations of production and exchange and their determination of the nature of land use. Among the most significant in the Canadian context is Fowke's (1946) *Canadian Agricultural Policy* in which he provided an interpretation of Canadian agriculture policy and the place of agriculture in the broader framework of the economic and political life of Canada. Fowke viewed Canadian agriculture as a means for the defense of territory and trade routes, a provider of staple trades, and opportunities for investment (Phillips, 1978). More recent political-economic approaches to the study of agriculture acknowledged the farm as part of a broader agro-food system, embedded in a web of economic, social, cultural, and political dimensions (see, for example, Bowler and Ilbery, 1987; Cloke et al., 1990; Marsden, 1988; Marsden et al., 1986; Page, 2003; Wallace, 1985). The initial work on agriculture from a political-economy perspective was criticised for its emphasis on structural processes in agricultural production (macro-economic factors) that render farmers to the role of insignificant decision-makers, overlooks farm- and farm-household dynamics, and neglects certain institutional and technical arrangements of farming (Buttel, 1996; Whatmore et al., 1987). In addition, there was the re-emergence of the agrarian debates, which drew parallels between the changes affecting agriculture in the 1890s (see, for example, Kautsky, 1988; Lenin, 1967) and those occurring a century later (see, for example, Byers, 1982; Goodman and Redclift, 1981; Watts, 1996; Watts and Goodman, 1997). This work, however, tended to neglect factors external to the agricultural system: the role of the state, politics, and culture. The shortcomings of the early work in political-economy and on agrarian change were addressed by injecting frameworks such as food regimes and regulation theory that encompass global markets, geopolitics, and international regimes (Robinson, 2004).

The introduction of the concept of food regimes into agricultural geography represented a shift beyond the concern for production on farms to one dealing with the geography of food. Researchers began to consider the entire food system from upstream supply to farms through farm-based production to downstream manufacture, marketing, and distribution (see, for example, Friedmann, 1982, 1987, 1990, 1993; Friedmann and McMichael, 1989; Goodman and Redclift, 1991; Lawrence and McMichael, 2012; McMichael, 2009, 2010, 2012, 2013; McMichael and Myhre, 1991).

Geographers have focused on several research areas. The relationship between international food regimes and agricultural structures and the consequences of the new international divisions of labour in which transnational corporations have developed production facilities in the global South (Jarosz, 1996; Sayer, 1995; Sayer and Walker, 1992); and the linking of accumulation strategies to employment and consumption norms, types of state regulation and legislation, and household livelihood and consumption practices (Gorton et al., 2011; Horlings and Marsden, 2011; Katz, 2001; Young, 1997). The concept of food regimes has been criticized on different grounds. Some authors claim that the concept is of little value in terms of explaining the dynamics of agricultural change in specific countries (Moran et al., 1996), and neglects the role of human agency in affecting changes in the global food system (Goodman and Watts, 1994).

A related approach to food regimes is that of regulation theory (Aglietta, 1974; Boyer, 1990; Lipietz, 1992). The central concept in regulation theory is the regime of accumulation, a historically distinctive and relatively long-lived form of capitalist accumulation based on a particular nexus of a production/consumption mode of regulation. With respect to the agro-food system, it has been argued that there was a movement away from one era to another that is symbolized by the changing nature of the regulations governing production. One example was the move from productivism to post-productivism, which had distinct parallels with the move from Fordism to post-Fordism in that it implies a move to different work/production practices, different relations of production, and changes in the regulations governing production. Although there are still regulations encouraging farmers to maximize production, and others dealing with agricultural over-production vis-à-vis demand, these exist alongside ones linking over-production and support for the environment, competing claims on land use, and issues of food quality, purity, and taste (see, for example, Flyn and Marsden, 1992; Guthman, 1998; Marsden, 1992, 2013; Pritchard, 1999). Some authors have been critical of this perspective arguing that rather than witnessing a shift towards post-productivist agriculture, the dominant framing is in favour of a neoliberal regime of market productivism, leading to the further integration of large parts of international and European agriculture into the agro-food circuits of capital (Potter and Tilzey, 2005). More generally, other authors claim that the regulation approach is too reductionist in that it relates economic growth and decline to the development of institutions governing the relationship between wages and labour and associated balances of class power, questioning the extent to which different reactions of national institutions to developments of the world economy can be combined into a generalized model (Brenner and Glick, 1991).

More recent years have seen the emergence of perspectives that have challenged the approaches that fall under the broad category of political-economy. Authors emphasized the way farmers develop locally based strategies, agro-ecological approaches, and household resources to adapt to changing economic circumstances (see, for example, Bell, 2004; Jarosz, 2011; Morgan et al., 2010; Tornaghi, 2014; Winter, 2005). Moreover, approaches that operate in a system or network framework, such as actor-network theory (ANT) (Latour, 1993; Whatmore, 2002) were introduced in the 1990s. ANT defines an actor-network as the interaction between a set of human 'actors' and the circulation of non-human 'intermediaries' in a network. ANT has been applied to understanding the dynamics of the agro-food system by focusing on the multiple sets of contingent relations in the operation of different actor-networks. Some of these studies construct rural areas as an actor-network in which farming activities are connected not only to individuals, agencies, institutions, corporations, and governments, but also to non-human intermediaries such as scientific technologies and material forms (see, for example, Higgins, 2006; Juntti, 2012; Lee et al., 2014; Manzungu and Dzingirai, 2012; Tanaka and Juska, 2010; Wood, 2007). Geographers using actor-network theory have posited non-humans as potential agents (see, for example, Whatmore, 2002). Agency is regarded as relational and arises out of the interactions or associations of a plurality of humans and non-humans. Accordingly, it becomes just as important to attend to such things as microbes, technologies, and corporeality as it does to institutions and capitalists. In this respect neither nature nor society has ontological priority.

Other authors have been critical of agro-food studies that adopt an ANT approach claiming that general social processes that condition the concrete are substituted with a voluntarism that is shaped by the narratives of specific groups therefore reinforcing a form of structural determinism of the power of the groups that project them (Buttel, 1998). This raises the question of how political and economic social forms of power are being generated in the different types of actor- (food) networks now emerging. At the very least, what is required is a more systematic conceptual and empirical focus, which continues to critically analyze both the state and food governance more generally, and key privately organized actors (Marsden, 2000).

2.2.2 Agricultural Biotechnology

Drawing on the insights from agricultural geography various perspectives have been advanced in the academic literature that examine the development, adoption, and production of GM crops. These contributions may be divided into three broad themes that are overlapping and interrelated: the first theme revolves around political-economic perspectives. Employing the food regime and regulation theory approaches to understanding the historical development of agriculture and the formation of the agro-food system, some authors have argued that the legal and regulatory framework associated with the introduction of agricultural biotechnology is being used as a new form of capital accumulation; one that expropriates farmers' control over the production process and shifts it to the corporations that are the technology's developers. This accumulation strategy has important local and global implications given the high salience that agriculture has for both farmers and for a public concerned with food access (Burrows and Kloppenburg, 1996; Dowd-Uribe, 2014; Essex, 2016; Otero, 2008, 2012; Otero et al., 2013; Otero and Lapegna, 2016; Roff, 2008). In particular, authors have drawn on and developed conceptual tools such as appropriationism (the replacement of elements of the production process with industrial ones) and substitutionism (the replacement of agricultural end products with industrial ones) introduced by Goodman, Sorj, and Wilkinson (1987) to provide an analytical framework through which many historical and current developments in agriculture can be viewed. Genetic modification in agriculture, it is argued, greatly expands the number of traits that can be introduced into plants and consequently opens up new possibilities for appropriationism and substitutionism (Friedmann, 1993; Pechlaner, 2010; Ramachandra and Ravishankar, 2000).

Other authors, following a similar line of argument, have examined the effects that the technology's associated proprietary framework has on capital accumulation strategies. Agricultural biotechnology has heralded a major breakthrough in privatization strategies around the 'seed' evidenced in patents, contracts, and related legislation. It has been argued that interrelated developments in science and technology, agricultural biotechnology, neoliberal ideology, and IP rights have successfully overcome the seed's inherent obstacles to capitalist accumulation (Goto, 2013; Kloppenburg, 2004; Kuyek, 2007; Mascarenhas and Busch, 2006). The privatization of germplasm provides an exemplar of capital's struggle to accumulate in agriculture, given the natural limitation of the seed's reproducibility, and of the technology's seemingly decisive role in this struggle (Kloppenburg, 2004; Peekhaus, 2013; Prudham, 2007; Prudham and Morris, 2006; Ramey, 2010). In the US and Canada, for example, support for IP rights has been demonstrated through a regulatory reluctance towards articulating limits to such rights with respect to the new category of self-propagating inventions. The granting of general utility patents on plants and/or components of plants was not a forgone conclusion, but required extensive effort on the part of industry, and a supportive national (and international) regulatory environment.

The second theme in the academic literature revolves around developmental perspectives on the development, adoption, and production of GM crops. This includes international reports from organizations such as the CGIAR, the FAO, the IAASTD, the OECD, the United Nations Development Programme (UNDP), the World Bank, and the

European Commission. These studies assess a wide range of issues including: the importance of agricultural biotechnology for addressing population growth and poverty; the development of science and technology in agriculture in developed and developing countries; the economic effects of the adoption of GM crops on farm income; GM crop technology adoption levels; production effects of specific GM crops; trade regimes and related issues; health and environmental impacts; GM crops and food safety and security; related emerging technologies such as biomaterials and biofuels; risk assessment and management; and policy development, support, and communication (see, for example, Barrows et al., 2014; Brookes and Barfoot, 2013; CGIAR, 2000; European Commission, 2010; FAO, 2004, 2005, 2011; IAASTD, 2009; James, 2015; Mannion and Morse, 2012; OECD, 2009; UNDP, 2001; World Bank, 2007). In general, these studies claim that the adoption of GM crops has resulted in improved productivity and profitability for millions of farmers in both developed and developing countries. Also, agricultural biotechnology applications make a significant contribution to the alleviation of poverty and hunger and to the doubling of food, feed, and fibre production in developing countries. Finally, GM crops are considered part of the solution to preventing additional food crises and major social disruptions.

Other authors have been more skeptical about such findings. The idea that science and technology can easily be transferred from one context to another to wipe away complex conditions that give rise to poverty and environmental degradation has been widely challenged from a variety of different perspectives (see, for example, Altieri and Rosset, 1999; Chataway, 2005; Das, 1999, 2002; Dibden et al., 2013; Keeley and Scoones, 2003). The incentives and institutional relations of the structure of GM crop research, it has been argued, requires a vastly more advanced infrastructure, expertise, and expense than do earlier methods of crop improvement. Most of the basic research and innovation needed to create functional GM crops has been done in the academic institutions of developed countries (Etzkowitz, 1997; Freidberg and Horowitz, 2004). Moreover, IP laws combine with incentive structures among academic researchers, universities, and corporations with devastating effects for resource-poor small-scale farmers (DeVries and Toenniessen, 2001). One example of such effects is the complex relationship between Bt cotton and farmer desperation in the high suicide area in Andhra Pradesh, India. The unrecognizability and frenetic change in the cotton seed market wreaked havoc on the agricultural practices, livelihood, and well-being of small-scale resource-poor farmers. It is precisely the most vulnerable people who are at risk (Stone, 2007). Lastly, some authors claimed that biotechnology enables new potential for monopoly control of seeds and global bio-piracy that plunders genetic resources of indigenous peoples and poor nations to make corporate property (Shiva et al., 2000). Poor farmers, according to this view, will be crushed by bondage to multinational monopolists, re-subordinating poor nations to neo-colonial control. The most excoriated mechanism has been the so-called 'terminator technology', widely (but falsely) charged to Monsanto, the primary target of global protest. Critics also see the poor as threatened by environmental degradation, unsafe foods introduced through foreign aid and public distribution systems, or allergenicity from novel proteins (Herring, 2007; Shiva, 2000; Stone and Glover, 2011). In contrast to such views, some authors have pressed the case that GM crops are especially suited for small-scale resource-poor farmers because the technology is self-contained and could aid cultivation without altering agricultural practices or even being understood by the farmer (Byerlee and Fischer, 2002; Wambugu, 1999).

The third theme in the academic literature revolves around civil society perspectives on the development, adoption, and production of GM crops. This work has included authors that examine anti-GMO social movements (see, for example, Andrée, 2011; Eaton, 2009; Hall and Moran, 2006; Harsh, 2014; Heller, 2006; Magnan, 2007; Muller, 2006; Purdue, 2000; Reisner, 2001; Roff, 2007; Schurman, 2004; Schurman and Munro, 2006). Much of this work focuses on movements in the global North where resistance has achieved a level of success, for example, by pressuring sub-national, national and European levels of authority to implement moratoria on the production and/or importation of GM crops and foods. In addition, a growing literature exists about producer attitudes to GMOs, the incentives to adopt GM crops, and the economic costs and benefits of adoption (see, for example, Berwald et al., 2006; Bullock and Nitsi, 2001; Fulton and Keyowski, 1999; Goldsmith, 2001; Hall, 2008). Producers are thus recognized as actors that can influence the commercial success of GM crops. In the Canadian case, the strong opposition to the adoption of GM wheat, it has been argued, has illustrated the historical, political, and cultural significance of wheat farming in the Canadian prairies, and its role in crop rotation, seed saving, and the economic viability of farmers. Farmers and consumers voiced concerns about environmental implications, international market opposition, and the lack of transparency in the formulation of policies and regulation of GM crops (Andrée, 2011; Eaton, 2007, 2013; Magnan, 2006; Marcoux and Létourneau, 2013; Prudham, 2007).

Attention has also been given to consumer demands in relation to GM crops. Geographers studying food and agriculture suggest that consumers (especially in the global North) are demanding foods with qualities such as local, organic, ecological, slow, fair, and ethical because of the failures of the industrial food systems to provide food safety, environmental sustainability, and public accountability (Marsden and Smith, 2005; Renting et al., 2003). These dynamics, it has been argued, are being shaped by broader economic shifts away from regimes of accumulation based on mass production and consumption to a more quality based production (the so-called shift from (quantity) productivist to (quality) post-productivist). This turn to quality food has opened up spaces for a politics of consumption that challenge the adoption and production of GM crops.

In addition has been a body of work that examines the politically charged disputes over GM crops which depend on various discourses about biotechnology in general and GM crops more specifically. These discourses establish knowledge claims that simultaneously undermine the case for GM crops as potential contributors to development and motivate opposition to GMOs. The diffusion of such claims has been made possible at the junctures of transnational networks, enabling the screening, weighting, theorizing, and disseminating of contentious empirical accounts. The academic literature on the topic is vast and includes opposing narratives. Some authors attribute opposition to ignorance including problems of symbolism, quaint attitudes, and pagan beliefs (Bond, 1999; Braun, 2002; Gusterson, 2005; Herring, 2007, 2009) while other authors challenge such perspectives (Bonny, 2003; Bryan, 2001; Jasanoff, 2005). Other authors have traced such debates in the media coverage. These studies focus on the way varying attitudes play out in public perception, consumer choice, and discourse and language about GM crops (Cook, 2004; Gusterson, 2005; Kalaitzandonakes et al., 2004; Nelson, 2005; Priest, 2001).

2.2.3 Gaps in the Academic Literature

The academic literature that examines the development of agricultural biotechnology and the adoption and production of GM crops provides many insightful theoretical and empirical contributions that leading scholars have made, however, some gaps remain. First, there is a lack of emphasis on the development of capitalism as it relates to the agro-food system including agriculture and agricultural biotechnology. Accordingly, technology is considered an exogenous and socially neutral force in the development of capitalism. The focus is primarily on how it impacts production and society. Technological development then appears as a technical issue or a relationship between inputs and outputs; an autonomous process divorced from its origins in capitalist competition and class relations. This determinist and indeed reified conception of technology obscures the social relations that affect its development (Bowring, 2003; Liodakis, 2003; Smith, 1997).

Second, the role of the state, in terms of its capitalist character, has been underemphasized. Here the state is considered an autonomous actor; an institutional ensemble that is independent of society. Accordingly, the state may formulate and pursue goals (e.g., agricultural biotechnology strategy, policy, and regulatory framework) that do not reflect the interests of specific social groups or classes. Such studies unduly separate the state and society therefore denying their interdependence and interpenetration and the existence of classes and class struggle inside the state and outside of it. This perspective problematically renders the intersection of the development of agricultural biotechnology with corporate interests a by-product, rather than a motivating force, of these processes. State action in relation to the development of agricultural biotechnology is regarded as 'neutral' or incidental to the capitalist accumulation process.

Third, there is little discussion about the interests underlying the construction of pro-GM crops discourses. The advent of GM crops is depicted as a technological phenomenon which originates from scientific progress the result of which is to either eradicate various societal ills (pro-GM crops discourses) or to merely propagate them (anti-GM crops discourses). While these studies stress the importance of the social elements and the actors responsible for the construction of various discourses surrounding GM crops, they supply neither a method to differentiate the most crucial associations nor a way to ascertain why they occur. As such, their explanatory capacity goes no further than the allusion to complexity among an endless array of social and scientific factors.

Fourth, studies that examine the economic effects of the production of GM crops rely on data and mathematical models to reach conclusions but do not explain them. In cases where some explanation is provided the analysis revolves around the conjunctions of events to make claims about causation with a tendency to obfuscate the unobservable social relations that might account or give the necessary conditions for those correlations. The result is a positivist and empiricist approach to understanding the economic effects of the adoption and production of GM crops.

2.3 An Alternative Theoretical Framework for Understanding the Development of Science and (Bio) Technology

In setting out an alternative theoretical framework for understanding the development of science and (bio) technology in the context of capitalism (see Figure 2.1), my emphasis is on a set of wider social processes (i.e., the predominant set of social relations that underlie production and exchange in capitalist societies) that condition the direction and character of the development of science and (bio) technology. I begin with an examination of two fundamental aspects of capitalist society: the social relations of production and the productive forces. The social relations of production refer to the relations of ownership and control over productive resources. The productive forces include technological implements such as mechanical (e.g., tractors) and biological (e.g., GM seeds and agrochemicals). My focus is on intra-class relations of competition as they relate to the technological aspect of the productive forces while abstracting from the capital-labour relation as a contributor to technical change. Competition impels capitalism towards perpetual revolutions in the productive forces. This occurs in different sectors of the capitalist economy, including the agricultural sector. Since farmers' income is remaining stagnant and in order for them to be competitive both nationally and internationally and produce crops at a low price, farmers seek new technologies such as GM seeds and associated agrochemicals (technological fix) since they cannot move their production sight to areas with lower production costs (spatial fix). Also, agribusiness corporations compete with each other in order to meet this demand by producing new technologies such as GM seeds and associated agrochemicals. Both of these commercial producers compete in their respective industries by either using a new technology (e.g., farmers producing GM crops) or producing a new technology (e.g., corporations producing GM seeds). These economic processes, however, are not automatic, but are mediated by the state, civil society, and discursive mechanisms and occur in specific historical and geographical contexts.

Technical change occurs during specific historical periods characterized by long cycles in the uneven development of capitalism and is fragmented into discrete geographical locations. Moreover, the capitalist state, which generally operates in the interests of capitalists, creates conditions for capitalist accumulation. The state does things which capitalists left to themselves are not able to do, for example, the procurement of costly R&D infrastructure that requires significant capital outlays. Also, sections of civil society aim to resist the expansion of the market for agricultural biotechnology. Lastly, discourses about agricultural biotechnology, scientific progress, and economic development are employed to sustain and legitimate the sale and use of GM crops. The result is unequal class outcomes when we compare how farmers have fared relative to agribusiness companies.

2.3.1 The Social Relations of Production and the Productive Forces

The contradiction between the productive forces and the social relations of production accounts for the historical development of a succession of modes of production, a development which is fundamentally based on the growth of human productive power and forms of society rise and fall as they enable or impede that growth. The contradiction between the productive forces and the social relations of production was articulated most succinctly by Marx (1970, 20) in the Preface to *A Contribution to the Critique of Political Economy*,

> In the social production of their existence, men inevitably enter into definite relations, which are independent of their will, namely relations of production appropriate to a given stage in the development of their material forces of production. The totality of these relations of production constitutes the economic structure of society, the real foundation, on which arises a legal and political superstructure and to which correspond definite forms of social consciousness.

Some authors give primacy to the productive forces over the social relations of production (see, for example, Cohen, 2001; Roemer, 1988; Shaw, 1978). One of the most influential proponents of this perspective was Gerald A. Cohen. According to Cohen (2001), the economic structure consists of the social relations of production alone, with the productive forces forming no part of it. Moreover, a productive force is not a social relation, "It is not something which holds between objects, but rather a property of an object…an object bearing that property, an object having productive power, and such an object is also not a relation" (2001, 28). The social relations of production correspond to the productive forces at a certain stage of the development of the latter. This implies that the productive forces have explanatory primacy over the social relations of production and therefore propound a technological interpretation of historical materialism.

For Cohen (2001, 32-55), the productive forces consist of the means of production and labour-power. The means of production include: the instruments of production (tools, machines such as mechanical and biological implements, premises in which production proceeds, and instrumental materials that producers work with); raw materials (what producers work on); and spaces (a particular volume of space in abstraction from whatever it contains). The development of the productive forces is largely the growth in the knowledge of how to control and transform nature, which is the development of labour-power (the productive faculties of producing agents including strength, skill, (scientific) knowledge, inventiveness, and so on). The social relations of production are either relations of ownership over persons and productive forces or relations presupposing such relations of ownership. By ownership, Cohen meant a relationship of effective control rather than a legal relationship. Since the social relations of production constitute the economic structure of a society, that structure is determined by the distribution in it of (effective) ownership rights over persons or productive forces. Also, Cohen claimed that along with the productive forces, persons are excluded from the economic structure. This is consistent only if the terms that bind the social relations of production do not belong to the structure that they constitute. Cohen (2001, 36) stated, "a description of an economic structure employs variables in places of expressions denoting persons and productive forces. It contains no names or descriptions designating particular persons and productive forces".

The primacy of the productive forces may be understood using two thesis: first, "*the nature of a set of production relations is explained by the level of development of the productive forces embraced by it* (to a far greater extent than vice versa)" (Cohen 2001, 134, italics in original) and second, "The productive forces tend to develop throughout history (the Development Thesis)…The nature of the production relations of a society is explained by the level of the development of its productive forces (the Primacy Thesis proper)" (Cohen 2001, 134). Although Cohen recognized the many ways in which the social relations of production condition the productive forces (see

Cohen 2001, 160-166), and the bearing this has on the primacy thesis, he claimed that Marx's general statements always awarded priority to the productive forces.

In sum, within a mode of production there is a correspondence between the productive forces and the social relations of production, and as a result, between the social relations of production and the political, legal, ideological, and other social relations (the second correspondence being one between the economic structure and the superstructure). The productive forces are given primacy. The social relations of production are determined by the productive forces, and they in turn determine the superstructure. These respective positions of the three elements in the causal chain acquire significance from their implications for historical development. Thus, the development of the productive forces leads to a contradiction with the social relations of production (which turn into their fetters, that is, restricts the use and development of the productive forces), and the intensification of this contradiction leads to the breakdown of the existing mode of production and its superstructure (see Figure 2.2).

Figure 2.2: Gerald A. Cohen's (2001) Perspective on the Contradiction between the Productive Forces and the Social Relations of Production

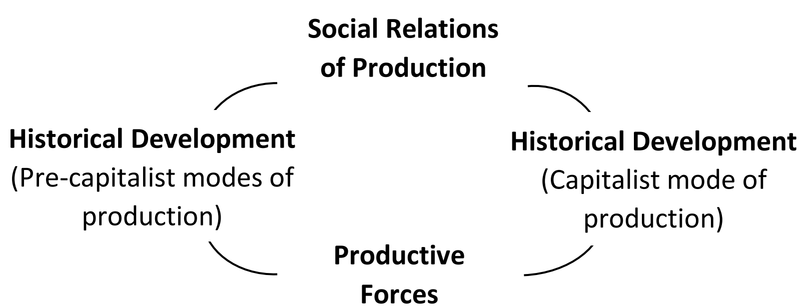
Productive Forces
Means of production (instruments of production – includes
mechanical and biological, raw materials, and spaces)
Labour-power (in its various qualitative aspects)
|
Social Relations of Production
(Economic structure and superstructure)
|
Historical Development

Cohen's interpretation, and others following a similar line of argument, have been the subject of considerable criticism (see, for example, Brenner, 1986; Harvey, 2006, 2010; Loeppky, 2005; Levin and Wright, 1980; Wood, 2007). An important consideration for some authors are the political implications of this perspective. It has been argued that Joseph Stalin's policy of rapid industrialization with its forced collectivization and political repression stemmed from his conception of the primacy of the productive forces, so that if the productive forces in the former Soviet Union became those of modern industry, the socialist relations of production would have had their proper basis (Levin and Wright, 1980).

Wood (2007) argued that the guiding principle of historical materialist analysis should be to prioritize historical process over technological determinism. The relations between producers and appropriators in the materialist explanation of historical movement may be understood using two broad categories of Marxist explanation: "The first situates production relations and class within a larger, trans-historical context of technological development. The other seeks specific principles of motion in every social form and its dominant social property relations" (Wood, 2007, 110). The distinction made here is not simply between Marxist theories that give primacy to the productive forces and those that give primacy to the social relations of production; rather, the emphasis is between theories that posit some general, trans-historical and universal law of development (which invariably means some kind of technological determinism), and those that stress the historical specificity of every social form (which generally means an exploration of the specific 'laws of motion' set in by the prevailing social relations between producers and appropriators).

Accordingly, Wood is critical of perspectives which understand historical change as a function of scientific and technological change. This is not to deny that scientific and technological change is associated with historical process; rather, it is to question whether or not particular trends in scientific and technological development constitute "the dynamic force that motivated historical change – either (causally) before or ('functionally') after the fact" (Wood, 2007, 132). Alternatively, in keeping with Marx's understanding of the functions of science and technology in the specific social form of capitalism, Wood (2007) provided an explanation which does not assume an inherently innovative historical development, but instead, understood innovation in the specific social form of capitalism. If a case can be made for the historical specificity of capitalist social relations of production, then it is reasonable to infer that there exists a historical specificity of the scientific and technological development that occurs under the auspices of those social relations (see Figure 2.3).

Figure 2.3: Ellen Wood's (2007) Perspective on the Contradiction between the Productive Forces and the Social Relations of Production

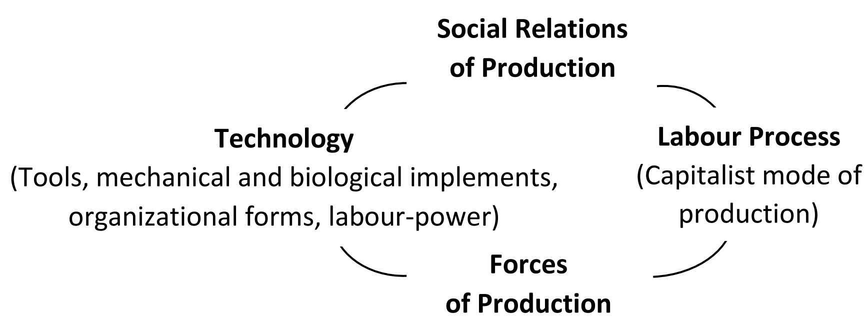


Moreover, it is not tenable to dismiss any autonomy in scientific practice. One cannot assume that the entire history of science, much of which occurred outside the boundaries of capitalist social relations, is simply the result of capitalism; however, for Marx, science and technology take on a special significance under developed capitalist industry. The critical moment "is completed in large-scale industry, which makes science a potentiality for production which is distinct from labour and presses it into the service of capital" (Marx, 1977, 482). The difference between pre-capitalist social forms and industrial capital is that the technologies circumscribed by human limits become an active agent with mechanical laws that surpass these limits. Marx (1977, 590) noted, "The principle of machine production, namely the division of the production process into its constituent phases, and the solution of the problems arising from this by the application of mechanics, chemistry, and the whole range of natural sciences, now plays the determining role everywhere". The production of scientific and technology itself becomes necessarily integrated into the dynamics of capitalism.

According to Harvey (2006), the productive forces in *Capital* are integrated into Marx's argument only when they are understood as a social relation specifically embedded in the capitalist mode of production. The flow of Marx's argument is "geared to unravelling the dialectical interpenetration of productive forces and social relations as the locus of contradictions which push capitalism perpetually into new configurations" (Harvey, 2006, 99). By productive force Marx meant "the sheer power to transform nature" (2006, 99). By social relations of production he meant "the social organization and the social implications of the what, how and why of production" (Harvey, 2006, 99). Marx considered the labour process in terms of both the productive forces and the social relations of production. Productive forces are integrated into political-economy as the power to create surplus-value for capital through commodity production. The social relations of production are the class relations that permeate production, exchange, distribution, and consumption.

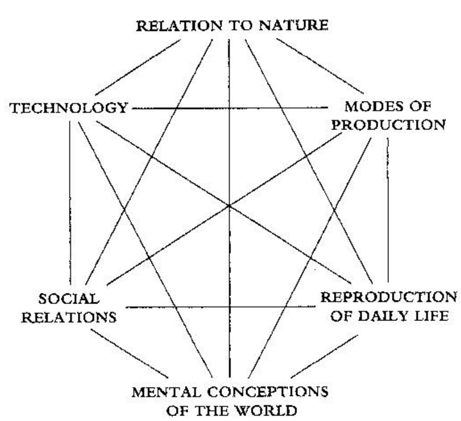
Technology may be directly described in terms of “the tools and machines used, the physical design of production processes, the technical division of labour, the actual deployment of labour powers (both quantities and qualities), the levels of co-operation, the chains of command and hierarchies of authority, and the particular methods of co-ordination and control used” (Harvey, 2006, 99). Marx viewed technology as the “concrete form taken by an actual labour process...the observable way in which particular use-values are produced” (Harvey, 2006, 99). The task then is to understand why particular labour processes take on specific technological forms. Harvey (2006, 100) does not equate the productive forces with technology, rather "technology is the material form of the labour process through which the underlying forces and relations of production are expressed" (see Figure 2.4).

Figure 2.4: David Harvey’s (2006) Perspective on the Contradiction between the Productive Forces and the Social Relations of Production



Furthermore, Harvey (2010, 189-201) claimed that Marx focused on a critical history of technology not only as a means to discerning radical technological shifts in the human evolutionary process, but also as a means to understanding how such shifts are dialectically related to whole modes of social life. Marx (Marx 1977, 493) stated, "Technology reveals the active relation of man to nature, the direct process of the production of his life, and thereby it also lays bare the process of the production of the social relations of his life, and of the mental conceptions that flow from those relations". Here Harvey (2010, 192) identified several concepts that are linked together in a configuration which provides a general framework for dialectical and historical materialism: technology, the relation to nature, the process of production, the production and reproduction of daily life, social relations, and mental conceptions. Technology and organizational forms internalize a certain relation to nature, the labour process, daily life, social relations, and mental conceptions. As a result of this internalization, a study of technology will reveal or disclose a great deal about each of those elements. Conversely, each of those elements also internalize something about technology. For example, a detailed study of daily life under capitalism will reveal or disclose a great deal about technology, the relation to nature, the labour process, social relations, and mental conceptions. All these elements constitute a totality and must be understood in their mutual interactions (see Figure 2.5).

Figure 2.5: The Interrelation between the Relation to Nature, Technology, Modes of Production, Social Relations, Reproduction of Daily Life, and Mental Conceptions



Source: Harvey, 2010, 195

The danger for social theory is to see one of these elements as a determinant of all the others, which inevitably leads to technological determinism, environmental determinism, labour process determinism, and so on.

Harvey links these relations back to Marx's (1970) base-superstructure model from the Preface of *A Contribution to the Critique of Political Economy*. He claimed that this formulation is at times erroneously interpreted in a causal or deterministic way: the economic base causes or determines the legal and political superstructure. Marx intended that the base-superstructure model operate dialectically. The way things are worked out in the realm of legal and political means of the superstructure are not ineffectual in relation to the deep concept of the circulation of value as capital. The purpose of the scientific method is to identify those elements that explain why certain things happen in society the way they do. In terms of our understanding of relative surplus-value, which explains why capitalism has to be technologically dynamic, firms have little choice over whether or not to invent because that is what the deep structure of capitalism mandates. The interesting question then is, how is growth going to occur and with what kinds of technological change? This forces us to think about the implications for those six elements.

In summary, the contradiction between the productive forces (i.e., the power to transform and appropriate nature through human labour augmented by the use of various instruments of labour such as mechanical implements including tools and machinery and biological implements including GM seeds and agrochemicals, raw materials, and spaces that form the means of production and constitute the necessary basis for productive labour) and the social relations of production (i.e., the historically evolving and geographically occurring social processes that shape the actual technology employed in the labour process and necessarily reflects the social relationships between human beings as they combine and cooperate in fundamental tasks of production) which accounts for the historical development of a succession of modes of production is applied to understand the dynamics of capitalism. While Marx abstracted from the specific details of actual technological changes, he nonetheless incorporated his conceptualization of technology by way of the abstract concepts productive forces and social relations of production in the concrete materiality of the labour process. The on-going quest by capitalists to appropriate surplus-value impels perpetual revolutions in the productive forces. Such revolutions, however, create conditions that are inconsistent with the further accumulation of capital and the reproduction of class relations. This results in an unstable and crisis prone capitalist system, though each crisis may be resolved through a restructuring of the productive forces and social relations of production, the underlying source of conflict is never eliminated.

2.3.2 Competition and Technical Change

To make the assertion that capitalist society has exhibited an extraordinary degree of technical change and organizational dynamism is self-evident. One of the challenges that remains is to explain how such technical change and organizational dynamism are intertwined in capitalist society rather than treating these dynamics as exogenous and autonomous. In this regard, several authors have examined the interrelationship of competition and technical change (see, for example, Elster, 1983; Fine, 1980, chapters two and six; Harvey, 2006, 119-125; Laibman, 1983, 1987/1988; Saad-Filho, 2002, chapter five; Smith, 1997, 2010; Stanislaw, 1990).

Competition impels capitalism towards perpetual revolutions in the productive forces. This occurs in the sphere of production and exchange. In the sphere of production, capitalists attempt to lower the costs of production in order to earn the profits necessary for the accumulation of capital that ensures their survival. Accordingly, there is a necessary tendency in capitalist production to introduce technology that: (1) decreases necessary labour time and increase surplus labour time; (2) allows a less skilled, less expensive, workforce to be employed; (3) lessens the 'pores' in the working day, therefore increasing the intensity of labour; (4) enhances capital's control over the production process; (5) reduces the turnover time of capital; (6) reduces the costs of constant capital; (7) generates a drive to appropriate surplus profits from highly productive units of capital in a sector and product innovations (Smith, 1997). The ways that these tendencies interact in a given socio-historical context is complex and contingent.

Regarding the sphere of exchange, Marx (1977, 1991) distinguished between two different types of competition in capitalism: intra-sectoral competition (in the first volume of *Capital*), which occurs between capitals in the same branch of industry producing identical use-values, and inter-sectoral competition (in the third volume of *Capital*), which occurs between capitals in different branches of industry producing distinct use-values. Marx argued that the conflicting forces of competition within and between sectors operate at different levels, with the former being more abstract and relatively more important than the latter.

Intra-sectoral competition explains the sources of technical change, the tendency toward the differentiation of the profit rate of capitals producing similar goods with distinct technologies, and the possibility of crisis of disproportion and overproduction. When firms compete and produce similar products, above average profits may be obtained only by attempting to become more efficient than other firms producing the same products, therefore reducing unit costs. This requires discipline and control in the labour process, mechanization, and the introduction of more productive technologies and economies of scale. These dynamics create a situation of competitive accumulation for all capitalists. Competitors will innovate as well as adopt every available technical improvement, eroding the advantage of innovating firms while preserving the incentive for further technical progress. This results in increases in economic efficiency and cheaper products in different sectors across the economy. There is also a tendency for larger capitals to benefit because of their ability to invest larger sums of money for longer periods, select among a broader range of production techniques, and hire the best workers. Although this may result in the elimination of weaker competitors, important counter-tendencies are the diffusion of technical innovations among competing firms, the ability of smaller capitals to undermine the existing technologies through invention and experimentation, and foreign competition (Fine, 1980; Saad-Filho, 2002).

The imperative of rapid accumulation for survival impels capitalists to search for high short-run conjunctural profits (Laibman, 1983). Their short time horizon, therefore, is not a historical accident or mere institutional datum; rather, it is a structural necessity. This, in turn, comes to dominate the engineering culture of a capitalist society, so that, quite apart from conscious directives, engineers who generate the menu of technical change-choices available in a given period will be constrained by the entire accumulated weight of past engineering practice, with a bias toward rapid mechanization in the interest of high short-term productivity gains and against the longer-term concerns of science (Laibman, 1987/1988).

Marx placed the interactions between individual capital (micro) and capital as a whole (macro) at the foreground of dynamics. In the competitive struggle to innovate and grow, each individual capital must act in terms of the immediately given situation, regardless of whether or not it is capable of foreseeing an outcome in which the parameters change owing to the combined impact of many capitals acting for self-preservation and growth. Pursuit of the maximum rate of profit associated with a new technique is a key element in establishing the dissonance between micro-intentions and macro-results that may impart an 'irrational' bias to the path of technical change, as well as other aspects of the long-term dynamics of the capitalist economy (Laibman, 1987/1988).

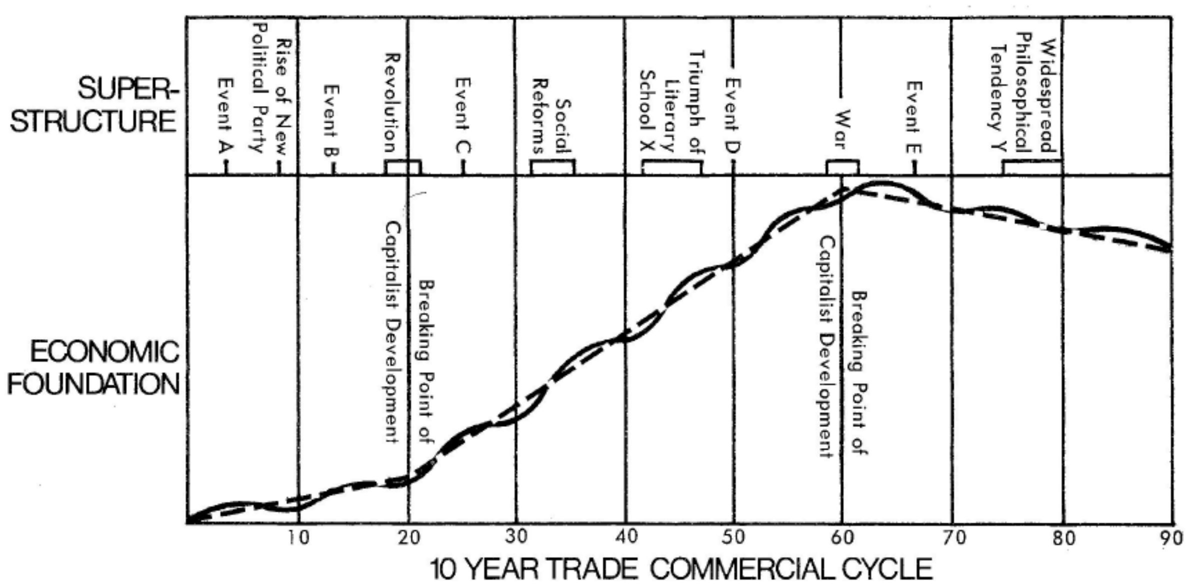
2.3.3 Cycles and Technical Change

The theory of the long cycles of economic development was initiated by Marxist economists at the beginning of the 20th century, but became primarily associated with the contributions of Nikolai Kondratiev and Joseph Schumpeter. Kondratiev identified three economic cycles of approximately 50 years duration: the first cycle witnessed a long wave of expansion from 1789 to 1809 followed by a long wave of relative stagnation from 1809 to 1849. The second cycle began with an expanding wave in

1849 that lasted until 1873, followed by a declining wave until 1896. The third cycle began with an expanding wave in 1896 which lasted until the economic crisis of 1920-1921 (Barnett, 2005). Kondratiev claimed that the economic crisis of 1920-1921 resulted from a disruption of equilibrium in the distribution of world markets and productive forces. He argued that the crisis was neither unique nor exceptional; its historical function was not to herald the imminent collapse of capitalism, but to facilitate the restoration of equilibrium. The concept of long cycles was invoked in order to put the problem into its proper perspective and thus to substantiate this conclusion (Day, 1976).

Trotsky (1973) challenged Kondratiev's assumptions by presenting a stylized diagram of capitalist economic growth based on the graph of English foreign trade (see Figure 2.6).

Figure 2.6: The Curve of Capitalist Development



Source: Trotsky, 1973, 278

Trotsky saw capitalism's 'moving equilibrium' periodically interrupted at clearly defined turning-points which altered its slope and rejected the concept of long cycles on the grounds that Kondratiev had obscured the difference between periodical cycles and separate historical periods. Trotsky (1973, 276-277) noted,

> The periodic recurrence of minor cycles is conditioned by the internal dynamics of capitalist forces, and manifests itself always and everywhere once the market comes into existence. As regards the large segments of the capitalist curve of development (fifty years) which Professor Kondratiev incautiously proposes to designate also as cycles, their character and duration are determined not by the internal interplay of capitalist forces but by those external conditions through whose channel capitalist development flows.

Trotsky sought to demonstrate that 'external conditions' and the relative autonomy of 'superstructural' phenomena precluded any automatic periodicity of long cycles.

Mandel (1978, 1995) made a systematic effort to reconcile Kondratiev's conclusions with the Marxist tradition in general, and with the views of Trotsky in particular. He claimed that Trotsky distinguished between 'long cycles' and 'long waves'. The concept of the long cycle implies a movement similar to that of the normal business cycle. The slump generates forces leading to the boom, in the same way as the boom generates forces leading to the slump. Mandel argued there is an asymmetry between the movements from an expansive long cycle into a depressive long cycle on the one hand, and the movement from a depressive long wave into an expansive long wave on the other hand. The former is more or less automatic and endogenous, and the latter is not automatic and requires exogenous system shocks: a radical change in the average rate of profit (and of surplus-value) as a result of wars and revolutions, a radical broadening of the market, and so on. For this reason a long wave's average duration may vary between 25 and 35 years. The prime movers of a long wave are the average rate of profit and the dimension of the world market. Only when both expand more or less simultaneously can the effects of a technological revolution come into their own.

Mandel (1978) substantiated this perspective by examining the peculiar inner dynamic to the succession of industrial cycles over longer periods of time. He claimed that capitalism has experienced three general revolutions in technology: first, the machine production of steam-driven motors since 1848; second, the machine production of electric and combustion motors since the 1890s; and third, the machine production of electronic and nuclear-powered apparatuses since the 1940s. Each technological revolution, he claimed, had been preceded by an over-accumulation of capital, or a situation in which a portion of the accumulated capital can only be invested at an inadequate rate of profit, and increasingly only at a diminishing rate of interest. Once the required capital had been accumulated, each technological revolution had been initiated by a combination of 'triggering factors' which raised the rate of profit, brought the new processes into production, and thus generated a long wave of rising investment and economic activity.

Mandel (1978) combined the analysis by W. Rupert Maclaurin and Gerhard Mensch to devise successive conditions for technological revolutions: (1) the propensity to develop pure science; (2) the development of current inventions capable of changing the whole basic technology of production; (3) the propensity to radical innovations; (4) the modification in the general conditions of capital accumulation that justify outlays for radical innovations; (5) the combined effect of: implemented radical innovation, rising profit rate, and accelerated economic growth, that launch the technological revolution. Technological innovations are centered on a specific form of labour organization in the labour process. During an expansionary long wave, when there is a rise in the profit rate, the reorganization of labour is less urgent because of the need for huge capital outlays to be depreciated and valorized. Conversely, toward the end of the expansionary long wave and a large part of the subsequent depressive long wave, when the decline of the profit rate is pronounced, there is an incentive to increase the rate of surplus value. This demands a profound change in the labour process, during which there is a general intensification of class struggle. Revolutions in the organization of labour, made possible through successive technological revolutions, historically grew out of conscious attempts by employers to break down the resistance of the working class and further increase the rate of exploitation.

Mandel’s attempt at reinforcing Kondratiev’s conclusions with more orthodox Marxist explanations has been criticized. For example, Day (1976) claimed that Mandel’s description of the ‘internal dynamic’ of technological revolutions suggests that some degree of rhythm is present; yet Mandel also agreed with Trotsky that social and political factors prevent the long cycles from exhibiting ‘natural necessity’. To overcome this difficulty Mandel avoids reference to long cycles (implying rhythmic movement) and instead refers to long waves with an undertone of expansion and long waves with an undertone of stagnation.

Schumpeter (1961, 132-136) integrated the concept of the Kondratiev cycle into his general theory of business cycles and was among a few economists to put technical change and entrepreneurship at the root of economic growth. He distinguished between invention (the realm of science and technology) and innovation (the commercial introduction of a new product). It is with profit in mind that entrepreneurs turn inventions into innovations, thus steering research efforts in particular directions. These decision processes are shaped by relative prices, institutional factors, and perceived market potential. Innovation, he claimed, is the meaningful space in which technical change needs to be studied, where technology, the economy, and the social-institutional context converge.

Technological innovations are not random; they tend to appear along with neighbouring innovations. Also, their evolution does not occur in isolation, but through a collective process that increasingly involves agents of change such as suppliers, distributors, consumers, and so on. The techno-economic and social interactions between producers and users weave complex dynamic networks that are clusters (Schumpeter, 1982, 167). Furthermore, major innovations tend to be inductors of further innovations and often stimulate entire industries; they demand complementary ones upstream and downstream and facilitate similar ones, including competing alternatives.

While Schumpeter's conceptualization of clusters of 'creative destruction' is useful for understanding the long cycles of uneven capitalist development, he arbitrarily divides invention from innovation leaving the related conditions surrounding the emergence of particular sciences and technologies completely out of the analysis. Moreover, for Schumpeter innovation emerges out of entrepreneurship and not class struggle therefore separating conceptually entrepreneurs from capitalists. Here we have no motive for invention or innovation. While such an analysis relates the development of science and technology to capitalist social formations, the former deterministically determines the latter in advanced industrial societies (Loeppky, 2005).

The work of Schumpeter has subsequently been drawn upon by neo-Schumpeterians (see, for example, Dopfer et al., 2004; Dopfer and Potts, 2008; Dosi, 1982, 1988; Dosi and Grazzi, 2010; Freeman, 1982, 1994; Freeman and Soete, 1997; Pavitt, 1999, 2001; Winter, 1982, 1987). In contrast to the emphasis on equilibrium and efficient allocation within given constraints associated with neo-classical economics, neo-Schumpeterians are more interested in the disequilibrium of processes through which new technologies come to displace pre-existing technologies and how constraints on economic development may be transcended. A useful distinction often made in the neo-Schumpeterian literature is between the micro (innovation and learning behavior in the firm), meso (innovation-driven industry dynamics), and macro (innovation-driven economic growth and competiveness) levels of the economy (Dopfer et al., 2004).

Beginning at the micro level, the conception, design, and production of any technology often involves sequences of cognitive and physical acts. The cognitive acts identify the inputs that are to be acted on and any required equipment, and the physical acts specify the actions that need to be taken to achieve a desired outcome. Although one single person may possess the full set of skills required to move from the raw inputs to the final output, this is usually not the case. In the domain of industrial technologies, the requisite knowledge and skills are distributed across many individuals and a crucial issue concerns when and how they are called for. The success or failure of these processes depends on the structure and dynamics of procedures in the combination of elementary cognitive and physical components underlying the intra- and inter-organizational division of labour and its dynamics. Input/output relations are essentially the by-product of successful attempts to change procedures and designs in desired directions. The mappings between procedure-centred and input/output-centred representations of technologies are crucial for any theory of production (Marengo and Dosi, 2005; Marengo et al., 2000; Rivkin and Siggelkow, 2003).

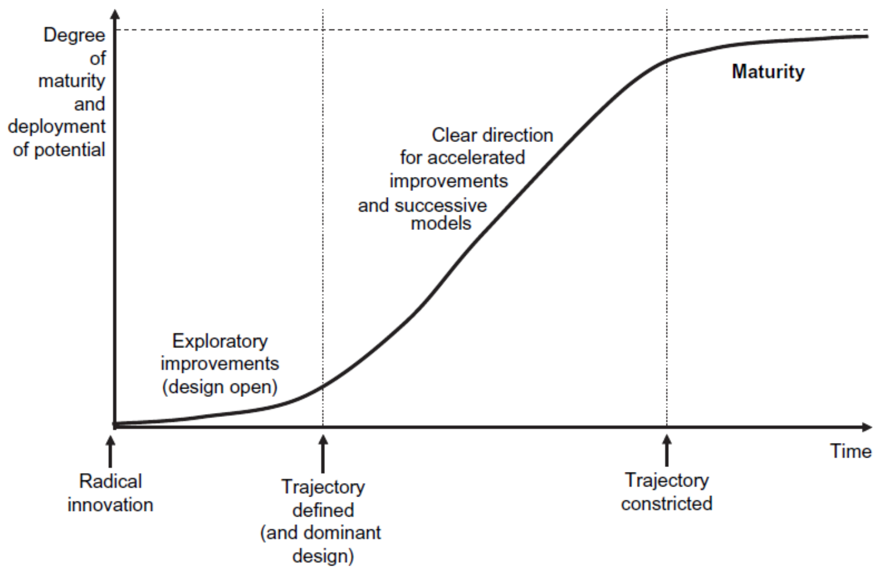
The procedures through which firms operate entail organizational routines. A routine is “an executable capability for repeated performance in some context that has been learned by an organization” (Cohen et al., 1996, 683). According to Nelson and Winter (1982), routines (1) embody a good part of the memory of the problem-solving repertoires of any one organization; (2) entail complementary mechanisms of governance for potentially conflicting interests, and in turn, ensembles of routines are the building blocks of distinct organizational competences and capabilities; and (3) organizational capabilities involve some ‘meta-routines’, which govern and possibly challenge and modify ‘lower level’ organizational practices (e.g., the more incremental part of R&D activities, and recurrent exercises of ‘strategic adjustment’). Such ‘higher level’ capabilities go under the name of dynamic capabilities (Teece et al., 1997).

Procedures draw on specific elements of knowledge ranging from ‘theoretical’ or codified knowledge (general scientific knowledge to knowledge of highly specific engineering applications) to ‘know-how’ or tacit knowledge reflected in the procedures and organizational routines of those engaged in production (see Polanyi, 1958, 1962, 1966, 1967). Codified knowledge is readily available in the professional communities and can be transferred in formal and systematic language using formats such as blueprints or operating manuals. By contrast, tacit knowledge cannot be communicated in any codified way; it comes from direct experience. As such, tacit knowledge represents disembodied know-how that is acquired via the informal learned behaviour and procedures. Some tacit knowledge is associated with learning without awareness (Polanyi, 1966). Polanyi (1962) sums up tacit knowledge as an act of 'indwelling', the process of assimilating to ourselves things from outside. In addition, tacit knowledge cannot be directly or easily transmitted, as knowledge and task performance are individual and specific and involve the acquirer making changes to existing behaviour. Within the range of tacit knowledge itself, the less explicit and codified the tacit knowledge is, the more difficult it is to assimilate it (Nelson and Winter, 1982).

The combination of codified knowledge and the degree of tacit skills of individuals have manifold implications for patterns of innovation, the division of labour, and the presence or absence of markets for technology. The source of technological knowledge primarily emanates from business firms complemented by universities, public laboratories, and individuals in the industries of more developed economies. Technological knowledge has some important features that include (1) acknowledging some common features of information and knowledge in general, and with reference to scientific and technological knowledge in particular; and (2) distinguishing the specific features of technological knowledge and the ways it is generated and exploited in contemporary economies. This applies to the pre-existing knowledge leading to any discovery and also to the knowledge required to interpret and apply whatever codified information is generated. Moreover, there are costs involved in acquiring and using relevant technological knowledge and the uncertainty about its ultimate success (Dosi et al., 2008; Nelson and Winter, 1982; Winter, 1987).

Shifting the focus to the meso and macro levels, newly introduced radical innovations that make it to the market are subjected to a series of incremental innovations following the changing rhythm of a logistic curve (see Figure 2.7).

Figure 2.7: Trajectory of an Individual Technology



Source: Perez, 2010, 187

Changes generally occur slowly at first, while producers, designers, distributors and consumers engage in feedback learning processes; rapidly and intensively once a dominant design has become established in the market; and slowly once again when maturity is reached.

In addition to rhythm, Dosi (1982, 1984) suggested that innovations may be understood through the concepts of technological paradigms and trajectories that attempt to capture the common features of technological activities and the procedures and direction of technical change. A technological paradigm is based on three fundamental ideas: first, an understanding of what technology is and how it changes must embody the representation of specific forms of knowledge on which a particular activity is based. Such representation primarily concerns problem-solving activities involving tacit forms of knowledge. Accordingly, technology is a set of pieces of knowledge ultimately comprising selected physical and chemical principles, know-how, methods, experiences of successes and failures, and the physical devices and equipment. Second, paradigms entail specific heuristics and visions about 'how to do things' and how to improve them, often shared by the community of practitioners in each particular activity (e.g., engineers, firms, technical societies). Together these comprise collectively shared cognitive frames. Third, paradigms often employ basic templates of artifacts and systems which are progressively modified and improved. These basic artifacts can also be described in terms of some fundamental technological and economic characteristics. For example, an airplane is not only described in terms of inputs and production costs, but also in terms of take-off weight, speed, and so on.

The concept of technological trajectories is associated with the progressive realization of the innovative opportunities underlying each paradigm, which can be measured in terms of the changes in the fundamental techno-economic characteristics of artifacts and production processes. The core idea is that each particular body of knowledge or paradigm shapes and constrains the rate and direction of technical change. Moreover, learning is local (i.e., occurring in the neighbourhood of the techniques and architecture) and cumulative (i.e., building on past experiences of production, innovation, and problem-solving junctures). There is a structure to technological knowledge and there are relatively ordered patterns of technological innovation linked to specific routes to the solution of particular problems.

What holds for the technological paradigms and trajectories of individual technologies also holds in terms of the evolution of whole products in an industry and whole sets of interrelated industries. These kinds of interrelated dynamics are encompassed in what Freeman (1992, 81) referred to as technology systems. Technology systems describe how Schumpeterian clusters are formed and evolve. Rather than being simple improvements, the incremental innovations along the trajectory are new products, services, and even entire industries, building upon the innovative space inaugurated by the initial radical innovation and widened by its followers. This leads to the modification of the institutional context and the culture in which they occur, which in turn tend to have feedback effects upon the technologies, shaping and guiding the direction they take within the range of different possibilities. Maturity is reached when the innovative possibilities of the system begin to wane and the corresponding markets to saturate.

Just as individual innovations are interconnected in technology systems, these are in turn interconnected in technological revolutions. A technological revolution can be defined as "a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems" (Perez, 2010, 189). Perez (2002) identified five successive technological revolutions: The Industrial Revolution (1771); Age of Steam and Railway (1829); Age of Steel, Electricity and Heavy Engineering (1875); Age of Oil the Automobile and Mass Production (1908); and the Age of Information and Telecommunications (1971). Technological revolutions more generally are major upheavals of the wealth-creating potential of the economy, opening vast innovation opportunities and providing a new set of associated generic technologies, infrastructures, and organizational principles that can significantly increase the efficiency and effectiveness of all industries and activities.

The structure of each revolution includes a significant number of interrelated new products and production technologies, giving rise to new industries. From the point of view of the role they play in driving change, the core industries of each revolution can be ranged into four main categories: one, the motive branches, which produce the cheap inputs. Two, the carrier branches, which are the most visible and active users of the inputs and represent the paradigmatic products of the revolution. Three, the infrastructures, which are part of the revolution in terms of technology and whose impact is felt in shaping and extending the market boundaries for all industries. Four, the induced branches, which encompass a set of industries that may be seen as indispensable to facilitate the maximum diffusion of the core industries (Perez, 1983, 1985).

The techno-economic paradigm is articulated through the use of new technologies as they diffuse and multiply their impact across the economy and eventually also modifies the way socio-institutional structures are organized. The construction of a techno-economic paradigm occurs simultaneously in three main areas: one, in the dynamics of the relative cost structure of inputs to production where new low and decreasing cost elements appear and become the most attractive choice for profitable innovation and investment. Two, in the perceived spaces for innovation, where entrepreneurial opportunities are increasingly mapped for the further development of the new technologies or for using them advantageously in the existing sectors. Third, in the organizational criteria and principles, where practice keeps showing the superior performance of particular methods and structures when it comes to taking advantage of the power of the new technologies for maximum efficiency and profits. The principles of organization for maximum efficiency and effectiveness embodied in the techno-economic paradigm gradually spread out of the business world and into government and other non-profit institutions. Organizational inertia is a well-known phenomenon of human and social resistance to change. In the market economy, however, inertia is overcome by competition, which, by showing the direction of success, serves as a guide to best practice and as a survival threat to the laggards. Eventually, the new techno-economic paradigm becomes the shared, established and unquestioned 'common sense' both in the economy and in the socio-institutional framework creating a clearly biased context in favour of the trajectories of the technologies of the revolution and their use across the economy (Perez, 2007, 2009).

To summarize, technical change occurs during specific historical periods characterized by long cycles in the uneven development of capitalism. Although the periodic recurrence of minor cycles condition the internal dynamics of capitalism, larger segments of the capitalist curve of development are determined by the 'external conditions' through which these processes flow. The external conditions and the relative autonomy of 'superstructural' phenomena determine the uneven flow of capitalist development that incorporates perpetual revolutions in technology.

Invention and innovation occur in clusters of 'creative destruction'. New technologies displace pre-existing technologies in an attempt to transcend constraints on economic development. This occurs at the micro (innovation and learning behavior in the firm), meso (innovation-driven industry dynamics), and macro (innovation-driven economic growth and competiveness) levels of the economy. Micro processes include cognitive acts that identify the inputs that are to be acted on and any required equipment, and physical acts that specify the actions that need to be taken to achieve a desired outcome. These are embedded in procedures and organizational routines that draw on specific elements of knowledge ranging from 'theoretical' or codified knowledge (general scientific knowledge to knowledge of highly specific engineering applications) to 'know-how' or tacit knowledge reflected in the procedures and organizational routines of those engaged in production.

At the meso and macro levels, newly introduced radical innovations that make it to the market are subjected to a series of incremental innovations. Changes generally occur slowly at first, while producers, designers, distributors and consumers engage in feedback learning processes; rapidly and intensively once a dominant design has become established in the market; and slowly once again when maturity is reached. In addition, technological paradigms and trajectories attempt to capture the common features of technological activities and the procedures and direction of technical change. What holds for the technological paradigms and trajectories of individual technologies also holds in terms of the evolution of whole products in an industry and whole sets of interrelated industries referred to as technology systems. Just as individual innovations are interconnected in technology systems, these are in turn interconnected in technological revolutions. A technological revolution can be defined as "a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems" (Perez, 2010, 189). The structure of each revolution includes a significant number of interrelated new products and production technologies, giving rise to new industries. As a result, the techno-economic paradigm is articulated through the use of new technologies as they diffuse and multiply their impact across the economy and eventually also modifies the way socio-institutional structures are organized.

2.3.4 Geography and Technical Change

Geographers have also drawn on the contributions of Kondratiev and Schumpeter in their understanding of technical change. Long waves theorizing has generated hypotheses about and insights into the dynamics of capitalist development and the relationships between uneven development and the generation and geographical implications of long waves (see, for example, Coe et al., 2013, chapter nine; Dicken, 2011, chapter four; Hall, 1985; Hall and Preston, 1988; Knox et al., 2003; Marshall, 1987).

The geographical implications of long waves are profound and may be associated with the rise and fall of regions and places of production (Hall, 1985; Massey, 1988). Broadly speaking, there are two schools of thought on the implications of long waves for geographically uneven development. Hall (1985) argued that places are differentially endowed with respect to the development and growth of new technology, so that uneven development will and should result and that such differences should be intensified in policies of economic growth. By contrast, other authors argued that technical change is facilitative and places may be adapted to such change (Marshall, 1987; Massey, 1988). Marshall (1987) pointed out that new or ‘high’ technology rarely represents a sudden or complete break with the past and that ‘low’ technology may be modified by high technology via process innovation. Insofar as geography represents an integral part of the conditions of existence of productive activity, it seems likely that the geography of the generation of long waves is not reducible merely to local conditions of innovation, but to contradictions and potentials in the geographical structure of economic development at particular places and points of time to which technical change and innovation may represent a positive response.

Geographers have highlighted the importance of regions for an understanding of technical change (see, for example, Cooke and Schwartz, 2007; Fagerberg et al., 2005; Gertler and Vinodrai, 2009; Mackinnon et al., 2002; Malecki, 2007, 2010, 2012; Rigby, 2003; Spencer et al., 2010). A regional economy may be crudely conceived as a collection of economic agents, firms, and workers embedded in a set of organizational and institutional structures that guide behavior to a greater or lesser degree. Regions are also repositories of accumulated knowledge, both codified and tacit. Region-specific knowledge bases consist of familiarity with the production of particular commodities and of specific techniques used in their production. They also include experience with organizational forms of different ways of separating production through the division of labour, managing inter- and intra-firm relations, and experience with institutional structures that regulate the environment in which economic agents operate. These knowledge bases incorporate behavioural conventions that shape the way in which knowledge is produced or obtained in the region. Since these pools of knowledge differ across space, technology may be differentiated geographically, along with the characteristics and determinants of technological change (Rigby, 2003).

A substantial literature exists on regional innovation systems (Asheim and Isaksen, 1997; Cooke, 1992, 1998, 2001; Cooke et al., 1997), learning regions (Archibugi and Lundvall, 2001; Bathelt et al., 2011; Lundvall and Johnson, 1994; Morgan, 1997) and localized knowledge economies (Asheim and Gertler, 2005) that foster the production of knowledge (Feldman and Kogler, 2010; Hudson, 2011). Critical in much of this work is the idea that different knowledge economies/learning regions produce different subsets of knowledge as the source of their competitive advantage. Regional innovation systems stem from the existence of technological trajectories that are based on knowledge and localized learning in a region. These can become more innovative and competitive by promoting stronger systemic relationships between firms and the region's knowledge infrastructure. They also stem from the presence of knowledge creation organizations whose output can be exploited for economically useful purposes by supporting newly emerging economic activity. The emergence of the concept of a regional innovation system coincides with the success of regional clusters and industrial districts in the post-Fordist era (Asheim, 2000; Asheim and Cooke, 1999) and the elaboration of the concept represents an attempt to understand the central role of institutions and organizations in promoting innovation-based regional growth (Asheim and Herstad, 2003; Gertler and Wolfe, 2004).

The regional innovation system can be thought of as the institutional infrastructure supporting innovation in the production structure of a region. The concept of region highlights an important level of governance of economic processes between the national level and the level of the individual cluster or firm (Asheim and Cooke, 1999). The region is increasingly the level at which innovation is produced through regional networks of innovators, local clusters, and the cross-fertilizing effects of research institutions. In varying degrees, regional governance is expressed in both private representative organizations such as branches of industry associations and chambers of commerce, and public organizations such as regional agencies with powers devolved from the national level to promote enterprise and innovation support (Asheim and Herstad, 2003; Cooke et al., 2000).

The systemic dimension of the regional innovation system derives in part from the team-like character associated with innovation in networks. Such relationships must involve some varying degrees of interdependence. As the interactive mode of innovation grows in importance, these relations are more likely to become regionally contained, especially in the case of specialized suppliers with a specific technology or knowledge-base. Such suppliers often depend on tacit knowledge, face-to-face interaction and trust-based relations and, thus, benefit from cooperation with customers in regional clusters, while capacity subcontractors are increasingly sourced globally. Further reinforcing the systemic character of the regional innovation system is the prevalence of a set of attitudes, values, norms, routines, and expectations; described by some authors as a distinctive ‘regional culture’ that influences the practices of firms in the region. It is this common regional culture, itself the product of commonly experienced institutional forces, that shapes the way that firms interact with one another in the regional economy (Asheim and Gertler, 2005).

Geographers have recognized the geographical patterns of specialization in the distribution of industries (Ellison and Glaeser, 1999), in techniques of production (Rigby and Essletzbichler, 1997, 2006), and in organizational and institutional formations

(Saxenian, 1994; Storper, 1997). Aggregation of these geographical differences has generated interest in the ‘knowledge-base’ of regions (Malecki, 2007, 2010; Quatraro, 2010; Todtling and Trippl, 2005). In particular, it has been argued that as developed countries have lost comparative advantage in manufacturing to developing countries, they have sought to promote knowledge-driven economies based on high value-added activities such as R&D. As a consequence of this shift, particular industrial sectors have been identified as crucial in the knowledge economy, not only because they enable new modes of interaction and learning (e.g., information technology), but also because they provide the knowledge-base for whole new sectors (e.g., agricultural biotechnology).

When one considers the actual knowledge-base of various industries and sectors of the economy, it is clear that knowledge and innovation have become increasingly complex. There is a larger variety of knowledge sources and inputs to be used by organizations and firms, and there is more interdependence and a finer division of labour among individuals, companies, and other organizations (Cowan et al., 2000). Nonaka and Takeuchi (1995) have pointed out that the process of knowledge generation and exploitation requires a dynamic interplay between, and transformation of, tacit and codified forms of knowledge as well as a strong interaction of people within organizations and between them. These knowledge processes have become increasingly inserted into various forms of networks and innovation systems at regional, national, and international levels.

Despite the general trend towards increased diversity and interdependence in the knowledge process, some authors have argued that the innovation process of firms is also strongly shaped by their specific knowledge-base, which tends to vary systematically by industrial sector (Fagerberg, 2005; von Tunzelmann and Acha, 2005). The knowledge-base may be distinguished between two types: synthetic and analytical (Laestadius, 1998). These types entail different mixes of tacit and codified knowledge, as well as different codification possibilities and limits. They also imply different qualifications and skills, reliance on different organizations and institutions, as well as contrasting innovation challenges and pressures.

A synthetic knowledge-base prevails in industrial settings where innovation takes place mainly through the application or novel combination of existing knowledge. This occurs in response to the need to solve specific problems arising in the interaction with clients and suppliers. Industry examples include specialized industrial machinery, plant engineering, and shipbuilding. R&D is in general less important than in other sectors of the economy. When it occurs, it tends to take the form of applied research, but more often it involves incremental product or process development related to the solution of specific problems presented by customers (von Hippel, 1988).

University-industry links are relevant, but they are clearly more significant in the realm of applied R&D than in basic research. Knowledge is created less in a deductive process or through abstraction than through an inductive process of testing, experimentation, computer-based simulation, or practical work. Knowledge embodied in the respective technical solution or engineering work is at least partially codified; however, tacit knowledge seems to be more important than in other types of activity, due to the fact that knowledge often results from experience gained at the workplace, and through learning by doing, using, and interacting. These forms of knowledge are often provided by professional and poly-technical schools, or by on-the-job training (Asheim and Gertler, 2005).

In contrast, an analytical knowledge-base dominates economic activities where scientific knowledge is highly important, and where knowledge creation is often based on formal models, codified science, and rational processes (e.g., agricultural biotechnology and information technology). Both basic and applied research as well as the systematic development of products and processes are central activities in this form of knowledge production. Companies typically have their own in-house research and development departments but they also rely on the research output of universities and other research organizations in their innovation processes. University-industry links and networks are thus important, and this type of interaction is more frequent than in the synthetic type of knowledge-base. Knowledge inputs and outputs in this type of knowledge-base are more often codified than in the case of synthetic knowledge. This does not imply that tacit knowledge is irrelevant, since both kinds of knowledge are always involved in the process of knowledge creation and innovation (Nonaka et al., 2000; Johnson et al., 2000).

The importance of codification in analytic knowledge reflects several factors: knowledge inputs are often based on reviews of existing (codified) studies, knowledge generation is based on the application of widely shared and understood scientific principles and methods, knowledge processes are more formally organized (e.g. in R&D departments), and outcomes tend to be documented in reports, electronic files, or patent descriptions. Knowledge application takes the form of new products or processes, which are more likely to constitute radical innovations than in those industries for which synthetic knowledge constitutes the principal knowledge base. New firms and spin-off companies (i.e., new market entrants rather than existing firms) are an important conduit for the application of knowledge embodied in these radically new inventions or products (Asheim and Gertler, 2005).

To sum up, technical change is fragmented into discrete geographical locations. The geographical implications of long cycles in the uneven development of capitalism are profound and may be associated with the rise and fall of regions and places of production. A regional economy may be crudely conceived as a collection of economic agents, firms, and workers embedded in a set of organizational and institutional structures that guide behavior to a greater or lesser degree. Regions are also repositories of accumulated knowledge, both codified and tacit. Regional innovation systems incorporate learning regions, and localized knowledge economies that foster the production of knowledge. Different knowledge economies/learning regions produce different subsets of knowledge as the source of their competitive advantage. The regional innovation system can be thought of as the institutional infrastructure supporting innovation in the production structure of a region. The systemic dimension of the regional innovation system derives in part from the team-like character associated with innovation in networks. The innovation process of firms is also strongly shaped by their specific knowledge-base, which tends to vary systematically by industrial sector. The knowledge-base may be distinguished between two types: analytical and synthetic. These types entail different mixes of tacit and codified knowledge, as well as different codification possibilities and limits. They also imply different qualifications and skills, reliance on different organizations and institutions, as well as contrasting innovation challenges and pressures.

2.4 The Development, Adoption, and Production of GM Crops

The contributions on the development of science and technology in capitalism provide the basis for understanding the historical and geographical development of agricultural biotechnology and the adoption and production of GM crops. The development of agricultural biotechnology is not simply the result of the autonomous processes of a purely technological phenomenon (i.e., the so-called ‘biotechnology revolution’), but capitalist social relations that demand innovation. This has been the result of the efforts of a conjunction of social actors (e.g., governments, corporations, and public institutions) and practices of scientific research and technological applications necessary for sustaining such processes amidst systemic contradictions. The outcome has been a R&D structure that broadly accommodates the needs of capital and promotes the patenting of life forms in agriculture, further concentration and centralization among multinational GM seed and agrochemical corporations, a discourse that sustains and legitimizes the production of GM crops by positioning agricultural biotechnology as a panacea for perplexing socio-economic problems such as (inter) national economic growth and development, a stagnate agricultural industry, health and environmental issues, population growth and poverty, and so on, and the unprecedented global adoption and production of GM crops.

2.4.1 The State and Civil Society

As Canada's economic situation steadily declined amid the economic recession and lagging manufacturing throughout the 1970s and 1980s, concern for the national economy and industrial performance emerged as major issues. The Government of Canada has for many years attested that the development of science and technology will reap great socio-economic benefits for the Canadian population (see, for example, Government of Canada, 2003; Health Canada, 2005). Canada's national biotechnology strategy was inaugurated to facilitate the potential of new recombinant DNA techniques that were being developed and support the regulatory and R&D activities of various federal departments and agencies. Innovation featured prominently as a policy goal that entailed a substantial spending program for: improving technological innovation and diffusion; developing 'strategic' technologies; assuring a highly trained workforce; supporting basic and applied research; controlling the effects of technology on society; and promoting a 'science culture' (Abergel and Barrett, 2002).

Public policy can influence innovation through a variety of policy instruments such as a stable economic environment aided by tax incentives for industrial research, monetary policy, direct subsidies for R&D, trade policy, regulatory frameworks and standards, and IP rights. Government innovation programs can involve creating a scientific and technological infrastructure that includes universities, research centers, government departments, educational and training institutions, financial institutions, and information network centers. By drawing on these instruments the Science Council of Canada directed attention to the importance of integrating technology into modern industrial processes. This entailed long-term restructuring of the economy, increased cooperation between the government and the private sector, and the strengthening of Canada’s technological capabilities by focusing on additional key areas to biotechnology such as engineering and computer technology (Abergel and Barrett, 2002).

The Government of Canada had succeeded in producing a regulatory framework based on the following principles: first, to build on current legislation where possible, rather than creating new legislation to govern new products which are developed. Second, to focus on product characteristics, rather than the method of production. All products developed through genetic engineering are assessed for unintended effects that may result from the introduction of foreign genes or DNA sequences. Third, to conduct evaluations for each product on the basis of its unique characteristics and to establish appropriate safety levels based on the best scientific information. In addition, the Government of Canada supported efforts towards harmonizing regulatory efforts with those of trading partners such as the US and other OECD member countries, recognizing that continued export of agricultural and other products and the removal of trade barriers depended on mutually consistent standards of safety and regulatory oversight. In 1988, AAFC began accepting applications to conduct Canada’s first confined research field trials for plants with novel traits (CFIA, 2007). Following vigorous marketing in Canada of GM canola, soybean, and corn (the three largest GM crops cultivated in Canada), Monsanto received regulatory approval from Health Canada to market herbicide resistant canola for food use in 1994, herbicide resistant soybean in 1996, and insect resistant corn in 1997 (Health Canada, 1997). From 1994 to 2014, Health Canada approved 184 novel foods (Health Canada, 2015). In 2015, GM corn, soybean, canola, and sugar beet accounted for 86%, 62%, 95%, and 100% respectively of total crop in Canada. Canada is an exporter of GM crops and products, including grains and oilseed such as canola, soybean, and corn. In the marketing year 2013/2014, Canada exported approximately 9.2 million metric tons (MMT) of canola, 3.4 MMT of canola meal, and 2.3 MMT of canola oil. Canada also exported 4.1 MMT of soybean, 92 thousand metric tons (TMT) of soybean oil, and 113 TMT of soybean meal. Canada's corn exports in 2013/2014 amounted to 1.9 MMT (Dessureault and Lepescu, 2015).

These developments may be understood in light of what Andrée (2005) referred to as the formation of a transnational biotech bloc. The transnational biotech bloc is spearheaded by the US, multinational corporations, and promotional and regulatory arms of government and civil society organizations. It has successfully (albeit unevenly temporally and spatially) promoted its own interests in the development of biotechnology as those of society as a whole. This has been accomplished through various discursive, material, and organizational practices including public relations campaigns, promoting IP regimes in plants and novel technologies, and gaining the support of public scientists, university departments, and regulatory structures. This has resulted in controversies that erupted both inside and outside the scientific community over issues such as gene transfer, the evolution of weed and insect resistance to modified traits, socio-economic impacts, among others (see Colwell et al., 1985; Halvorson et al., 1985).

Given the controversies surrounding the adoption and production of GM crops, the Government of Canada organized a series of meetings in 1993 that included representatives from government, academia, NGOs, and industry. While the purpose of the meetings at first appeared to be an effort towards more diverse debates around biotechnology, in reality they were predominantly confined around discussions about 'science-based' approaches to regulation and the economic advantages of adopting biotechnology. Following the 1993 meetings, branches of the Government of Canada produced documents and held consultations that emphasized the need to moderate the drive towards biotechnological innovation with considerations of the social, economic, political, environmental, and ethical dimensions (Abergel and Barrett, 2002).

The most critical assessment of the Government of Canada's biotechnology regulatory framework came in 2001 from the Royal Society of Canada's (RSC) Expert Panel Report on the Future of Food Biotechnology entitled *Elements of Precaution: Recommendations for the Regulation of Food Biotechnology in Canada* (see RSC, 2001). In response, the Government of Canada published an action plan and accompanying progress reports (see, for example, Government of Canada, 2001; Health Canada, 2013). In the spring of 2001, the CBAC held five consultations across Canada with industry stakeholders, academia, and civil society organizations to discuss the regulation of novel foods. Examining the CBAC's consultations between 1999-2003, Prudham and Morris (2006, 147) argued "that the CBAC GM foods project was, at best, a poorly conceived effort to engage with and respond to public concerns about GM foods, compromised by a prior commitment to commercialization. At worst, it was a cynical exercise coloured by a desire to secure and consolidate the legitimacy of GM foods in the midst of growing controversy". The authors link this to the CBAC's close ties with Industry Canada which resulted in discouraging many NGOs from participating in the CBAC's public consultations, therefore limiting their efficacy, and the CBAC's recommendations which highly favoured the biotechnology industry.

The development, adoption, and production of agricultural biotechnology in the Canadian context is not only the result of the efforts of individual capitals, but also those of the Canadian state. This raises issues about the relationship of the state to, on the one hand, capitalist social relations, and on the other hand, science and technology. Regarding the relationship of the state to capitalist social relations, an extensive debate exists in the Marxist literature (for reviews of this debate see, for example, Clarke, 1991a; Jessop, 1982). By virtue of its insertion into the structure of capitalist social relations, the state must promote value accumulation and reproduce the capitalist system. The social relations of capitalism require a regularized set of behaviours as well as the assurance of particular interaction between classes. The state continues to be the arbiter of that interaction and an entity which enforces an environment that is most amenable for the continuation of capitalist development. However, the particular form (e.g., policies that the state implements and the regulatory practices) the state takes and the outcomes are contingent on specific historical, geographical, and material conditions prevalent under capitalist social relations. Clarke (1991b, 168-169) stated, "The state does not constitute the social relations of production, it is essentially a regulative agency, whose analysis, therefore, presupposes the analysis of the social relations of which the state is regulative. The analysis of the capitalist state conceptually presupposes the analysis of capital and of the reproduction of capitalist relations of production, despite the fact that in reality, of course, the state is itself a moment of the process of reproduction". The Government of Canada's agricultural biotechnology policy, regulation, and funding regimes demonstrate the degree to which the economic is embedded in political structures of power as well as the reflexive nature of those political forms that depend in part on the economy for their continued existence.

Regarding the relationship of the state to science and technology, the Canadian state has been a critical non-economic actor in the drive toward agricultural biotechnology R&D aimed at commodity production. Interestingly, this is contrary to the neo-liberal rhetoric advanced since the 1980s about the state withdrawing from active participation in the economic markets and political regulation and control of advanced industrial capital (Harvey, 2005). In fact, the Government of Canada's agricultural biotechnology science and technology policy implementation, regulatory practices, and funding structures have become part of the general and external guarantees of the social conditions of production directed toward specific capitals as well as the sector as a whole. This demonstrates that in order for the state to ensure value accumulation and the reproduction of the capitalist system it must provide certain tangible, advantageous preconditions. The pursuit of growth policies necessitates an infrastructure that requires significant capital outlays which cannot be realized by individual capitals. Public policy is utilized to transfer social surplus value into particular sectors that not only give extra incentives to develop science and technology, but minimize the associated risks of venturing into such avenues (Hirsch, 1978; Loeppky, 2005). This is orchestrated, as has been discussed, in different ways, such as funding projects, tax relief incentives, infrastructure development, and so on. By accepting and promoting capitalist control over the development of biotechnology R&D, the Canadian state has been compelled to operate in ways that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

Moreover, civil society action has been effective, for example, by pressuring sub-national and national levels of authority to implement moratoria on the production and/or importation of GM crops and foods, and by directly challenging multinational corporations, the institutionalization of systems of private regulation, and the creation of new market categories (Hall and Moran, 2006; Harsh, 2014; Heller, 2006; King and Pearce, 2010; Schurman and Munro, 2009). In the Canadian case, the strong opposition to the adoption of GM wheat has illustrated the historical, political, and cultural significance of wheat farming, and its role in crop rotation, seed saving, and the economic viability of farmers. Farmers and consumers voiced concerns about environmental implications, international market opposition, and the lack of transparency in the formulation of policies and regulation of GM crops (Eaton, 2009, 2011, 2013; Magnan, 2007; Marcoux and Létourneau, 2013). Indeed, as Prudham and Morris (2006, 168) noted “the culturally loaded and embedded character of food as a class of commodities throws these tensions into sharp relief, and biotechnology – as a controversial suite of innovations with intersecting social, ethical, environmental, and health implications – provides rich opportunities for exploring how they work themselves out”.

2.4.2 Agricultural Biotechnology Discourse

The promotion of agricultural biotechnology has been generated at the international and national scales as part of (inter) national economic growth and development strategies, human progress and well-being, new knowledge and innovative products, food safety and security, environmental sustainability, and so on (see, for example, CGIAR, 2000; FAO, 2004; Government of Canada, 2003; Health Canada, 2005; UNDP, 2001; World Bank, 2007). One of the ways that the Government of Canada and the Canadian industry have sustained and legitimized the development, adoption, and production of GM crops is by constructing a pro-GM crops discourse. This has occurred in part by drawing on and propagating opinions from 'authoritative' sources including scientists and bureaucrats. A clear distinction is made between 'proper' science conceived by a narrowly defined 'expert' scientific community, and an ill-informed, naive, irrational, 'non-expert' public. The presumption is made that only opinions from scientists are valid while opinions from people with some scientific training, social scientists, or scientists that are opposed to GM crops, are for the most part simply dismissed. This perspective problematically makes the assumption that there is consensus among scientists regarding the development of agricultural biotechnology, when in fact the scientific debate has intensified both inside the Government of Canada's scientific community and outside of it (Tam, 1999). In addition, many studies by world-renowned scientists that highlight some of the negative impacts of GM foods have been published in peer-reviewed scientific journals despite the claim that such studies are flawed (see Verzola, 1999).

The sentiment of scientists that are proponents of GM crops has also been supported by government bureaucrats who do not permit including 'non-scientific' issues into regulatory assessments (Munn-Venn and Mitchell, 2005). By disregarding public concerns about biotechnology, the Government of Canada has maintained the perspective that the public, for the most part, is ignorant of the purported benefits that the technology will reap for Canadians. The Government of Canada has been actively promoting and supporting the development of the biotechnology industry for more than twenty-five years, and the multinational corporations that dominate the industry have been aggressively marketing the technology. Any attempts at questioning these processes and in any way hindering their development is met with obdurate resistance on the part of government scientists, bureaucrats, and the industry.

Given the authoritative role of scientists in the debate over GM crops, perhaps the most deeply rooted premise in the pro-GM crops discourse is that the answers to all questions about the development, adoption and production of GM crops are to be found exclusively in the confines of science. It is as though, once the scientific evidence can be agreed upon, then all the purported benefits of GM crops will automatically follow. This problematically implies that there are only two criteria surrounding the debate about GM crops, 'scientific' and 'non-scientific', and thus denies the validity of any other criteria (e.g., political, economic, cultural). To say that there are dimensions of the debate which are not scientific, however, is neither to dismiss scientific evidence nor to succumb to irrationality and prejudice. Although scientific findings are of critical importance, they do not encompass the entire debate over GM crops. The concern, in other words, has been much more with an appeal to science rather than with science itself. This reflects a common supposition that when a scientist speaks, in whatever forum, on whatever topic, and in whatever style, something of his or her authority carries over into other domains. In this way, science has come to be seen less as a way of proceeding or as a mode of thought, and more as the property of a particular group of people (Cook, 2005, 77-80).

In addition, there is a blurring of the distinction between genetic modification and natural processes, where the former is normalized as part of the latter, further legitimatizing the development of biotechnology as part of the history of the genetic manipulation of plants. This framing uncritically sustains “The “plant manipulation as progress” narrative”, where “domestication is genetic modification” (Stone, 2010, 384) and is often combined with the rhetoric about the benefits of GM crops for growing populations and feeding the poor. This is predicated on a form of neo-Malthusianism, which is a combination of Malthusianism and technological determinism (see Das, 2002, 60-65 for a related discussion on the Green Revolution technology). This suggests that there is a necessary relationship between GM crop technology and poverty reduction; however, the effect of the technology on poverty reduction is contingent. The only necessary effects of GM crop technology are technical or physical (e.g., greater yield), but the social effects (e.g., poverty reduction) are contingent. To make the claim that GM crop technology is beneficial for the poor is to grant technology much more power than it can possibly have. Also, underlying the technological determinism is the looming threat of population growth. The suggestion is made that a growing population can be fed from constant land only through the application of GM crop technology; however, a population’s relation to poverty directly or its relation to GM crop technology’s impacts on poverty is also contingent. Indeed the application of GM crop technology may increase food production, but whether or not this will result in reducing hunger in developing countries depends on a number of other factors (e.g., unequal power structures at multiple scales that affect the way food and other goods and services are produced and distributed, pauperization and proletarianization, income levels, social provisions, and so on).

Such statements and ideas have been given further legitimacy by asserting they are based on 'sound science'. This phrase routinely appeared in corporate and government websites and documents (see, for example, Bayer CropScience, 2009; Government of Canada, 2003; Health Canada, 2006; Monsanto, 2015b; Syngenta, 2013b). The phrase 'sound science' implies that there is another type of science that is 'unsound'. Science may be unsound in the sense that, while genuinely trying to follow scientific principles, it is full of mistakes: the methods are flawed, the evidence is wrong, or the calculations and inductions are incorrect. This is the kind of allegation which is often levelled by proponents of GM crops against the work of those scientists who are opponents of GM crops. Cook (2005, 95) noted, "The phrase 'sound science' is not in itself very sound. When used by scientists it can become self-congratulatory (rather like Monsanto's 'thoughtful dialogue') and circular: an epithet awarded by those on one side of a scientific dispute to themselves, and denied to their opponents".

By manipulating the pro-GM crops discourse, government and industry are actively engaging in strategies designed to control the discursive norms and institutional contexts that encompass agricultural biotechnology. This obscures the interest of capitalist accumulation more generally and those of individual capitals more specifically as the general interests of the Canadian public and farming communities and in part establishes and maintains the conditions conducive to capitalist accumulation. Since class struggle is inherent to capitalist relations of production, capital is compelled to engage in different strategies that provide the basis for accumulation in order to safeguard its existence. Any threat to the balance of power between classes that impedes capitalist accumulation is susceptible to such strategies (Peekhaus, 2013). This may be illustrated, as discussed, by the efforts of the industry with support from government scientific and financial capacities to engage in public relations campaigns, attacks on opponents, the maligning of unsympathetic scientific findings, intense lobbying, and the ability to disseminate information that is primarily sympathetic to the agricultural biotechnology industry. These strategies serve to constrain the discourse surrounding biotechnology in ways that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

In addition, the pro-GM crops discourse raises the issue about the relationship between the development of science and technology and capitalist social relations of production. One of the arguments posited by the government and industry in the construction of the discourse is the ostensibly ‘neutral’ development of science and technology under capitalist social relations of production and its corresponding specious and teleological claims about the putative capacity of science and technology to guarantee socio-economic progress. This perspective undermines the distinction between the development of science and technology in general and the development of science and technology under capitalist social relations of production, where the latter reflects the social relations under which it occurs. The appeal to science has provided government and industry a convenient strategy around which to circumscribe the social relations that underlie the pro-GM crops discourse and the adoption an production of GM crops. The development of science and (bio) technology is not a neutral affair. The conception of science and technology as asocial catalysts for progress independent of purposive human agency that benefits one group of people over another serves to obscure the social relations underlying the development of science and technology from the design and development stages of technological innovation. Such a conception not only relegates the social relations underlying new technologies to the instances of their application, but also casts their social effects on society as secondary and contingent. This suggests that scientists and technologists are the discoverers of laws and processes immanent in an exogenous natural realm. Progress is putatively rooted in the natural order of a world that triumphs over historical and social peculiarities. This discursive framing easily explains away social relations as unavoidable byproducts of history's teleological march of progress that can be mitigated through the perspicacious applications of new technologies (Leoppky, 2005).

Lastly, the pro-GM crops discourse obscures some fundamental aspects of the role of the development of GM technology in agriculture. The development of science and technology in agriculture has allowed for the reduction in the cost of agricultural production by increasing labour productivity, decreasing the reproduction cost of labour-power, and increasing surplus production at the societal level. The combination of labour with GM technology results in more output (farmers plant GM crops and get a higher yield than if they plant conventional crops). The increased output or the higher yield must be understood not only in terms of its use-value (more food to be consumed), but also in terms of its surplus-value (a given input of labour in a given time produces more output). Moreover, GM seeds producers, such as Monsanto, are driven by the capitalist profit motive. Billions of dollars have been invested in the R&D of GM seeds.

GM seeds producers, like any other commodity producers, rely on being the first to market so as to capture the largest market share and reap the greatest gains from their investment. The immediate objective of GM seeds production is not human sustenance and well-being but increase in profits. Accordingly, such discursive struggles have material consequences for the development, adoption, and production of GM crops, seed saving and production, multinational corporations, Canadian farming, the public, and food production in general.

2.4.3 Economic Effects of GM Crops Production on Farmers

The agricultural sectors of developed economies have experienced significant changes over the last four decades as farm size, intensity, capitalization, and specialization have dramatically moved from conventional configurations to what has been referred to variously as the third agricultural revolution, the modernization of farming, the industrialization of farming, and the restructuring of farming (Bowler, 2014). At the farm level, the general model is one of a shift from small-scale (less than 50 hectares) or medium-scale (51 to 150 hectares), generally mixed-enterprise (including two or more crops), to large-scale farms (151 or more hectares) (FAO, 2014). This is characterized by increased labour substitution, capital investments in land, and an increase in off-farm inputs such as mechanical (energy intensive machinery) and biological (GM seeds and associated agrochemicals). At the agro-food system level, the process involves integration between fewer and fewer industrialized farms, and between agribusiness and government. The latter two 'beyond the farm gate' elements are the most important aspects, influencing and controlling the restructuring process (Troughton, 1986).

Significant structural changes have occurred in Canadian farming. On the one hand, farm numbers in Canada have declined from 280,043 farms in 1991 to 205,730 farms in 2011 (Statistics Canada, 2012a). On the other hand, farm annual revenue and farm size increased. By 2011, farms with $1 million or more in annual revenue represented the fastest growing sector of Canadian agriculture. While these farms make up less than 5% of the total number of producers, they account for nearly half of Canada's food production (Statistics Canada, 2015a). In addition, subsidies continue to be a cardinal facet of Canadian agriculture and have had a major role to play in international trade despite the World Trade Organization's Agreements on Agriculture and Subsidies which have curbed agricultural subsidies in developed countries (see WTO, 2016; Swain, 2009). Although there has been a decrease since the mid-1980s in the Producer Support Estimate (PSE) as a share of gross farm receipts in Canada, as of 2015, the Canadian PSE amounted to $5.5 billion representing 9.4% of gross farm receipts (OECD, 2015).

Along with decreases in subsidies to farmers has been the policy shifts of AAFC since the mid-1980s from practices that benefit Canadian farmers, such as developing new publicly funded varieties that are resistant to drought, disease, and pests, in favour of contracts and partnerships with private clients to meet exclusively private-sector needs such as patented agronomic inputs. AAFC policy objectives have become increasingly market oriented: ensuring supply of diverse food products; making the marketing system more effective; and increasing the economic viability of the industry in a context of free trade (Moore, 2002). Despite such efforts, the collapse of world commodity prices in 1997 resulted in a significant drop in net farm income. The

Government of Canada responded by providing subsidies to farmers totaling $1.5 billion while the AAFC developed a performance framework that defined four main objectives: expanding markets; innovating for a sustainable future; building a strong foundation for the industry and rural communities; and providing departmental policies and services (Dakers and Forge, 2000).

The development, adoption, and production of GM crops has been in part a critical component of the drive in Canadian agriculture towards international competitiveness, productivity, economic growth, and innovation. This has been substantiated by significant expenditures on biotechnology R&D and science and technology R&D by the Canadian federal government totaling billions of dollars (see, Statistics Canada, 2010, 2012b, 2014b). In addition has been the important role of a handful of multinational corporations that have captured the global proprietary GM seed and agrochemical (herbicides, insecticides, and fungicides) markets. In 2013, the top six companies: Monsanto, DuPont, Syngenta, Bayer, Dow, and BASF accounted for 65% of the global proprietary GM seed market, and 75% of the global agrochemical market with sales of GM seeds, agrochemicals, and GM traits exceeding $65 billion per annum (ETC Group, 2015). As of 2015, the estimated seeded areas of GM corn, soybean, canola, and sugar beet (the four GM crops grown in Canada) were 86%, 62%, 95%, and 100% respectively of total crop area (Dessureault and Lupescu, 2015).

Farmers enter contracts with corporations, such as Monsanto, to cultivate GM crops. The contract between the farmer and the corporation significantly limits the farmer’s rights to the purchased seeds through a ‘no saved seed’ provision which prohibits saving seeds and/or reusing seeds from GM crops. In effect, the provision requires farmers to purchase GM seeds on an annual basis (Fernandez-Cornejo and McBride, 2002). This significantly alters the practices of generations of farmers who have selected, saved, exchanged, sold, and reused seeds. The value of a seed is realized not just in one harvest, but in the seeds it produces for future crops and the material it provides for future breeding. Patent protection over new genetic sequences is one legal mechanism that takes ownership of seeds out of the hands of farmers and allows corporations to capture value from them. In practice, this means that patents allow the corporation that developed a GM trait to forbid farmers from saving and replanting seeds with that trait, and public breeders from further selecting or developing.

Moreover, in Canada there has been an exponential rise in the cost of commercial seed compared to other farm expenses. For example, the annual rate of increase of commercial seed cost from 1986 to 2015 was 15% compared to 3.5% for machinery fuel or 5.1% for electricity (Statistics Canada, 2016a). More specifically, data from the Government of Alberta (2016) confirm the continuing rise in the cost of GM canola since 2012. For example, the cost of Bayer GM canola per 22.7 kg bag increased from $492.83 in January 2012 to $597.11 in January 2016 and the cost of Monsanto GM canola per 22.7 kg bag increased from $389.12 in January 2012 to $469.33 in January 2016. In addition to seed cost, farmers were required to sign and pay for a Technology Use Agreement (TUA) fee. For example, in 2011 Monsanto charged GM canola farmers a $15/acre TUA fee, which amounted to approximately $261 million in Canada over and above seed cost (NFU, 2013).

One of the common claims to justify the adoption and production of GM seeds is that they produce higher yields than conventional seeds. This claim is then linked to the assumption that higher yields result in higher incomes for farmers. Data confirms that there has been a general increase in yields since the production of GM canola (2% increase from 1996 to 2015), GM corn (3.1% increase from 1997 to 2015), and GM soybean (0.8% increase from 1996 to 2015) (Statistics Canada 2015b); however, increase in yields of the same crops also occurred prior to the introduction of GM traits. For example, the annual average increase in yields of conventional canola, corn, and soybean from 1966 to 1995 were 1.3%, 0.9%, and 1.4% respectively (Statistics Canada 2015b). Increases in yields as well as yearly fluctuations are attributed to many factors including: improvements in conventional breeding, geographical location, environmental changes, fertilizer and pesticide use, agronomic practices, farm machinery, and farm management (Veeman and Gray, 2009).

Moreover, data confirms that there has been a general increase in the gross farm income of Canadian farmers since the production of GM canola (from $6 million in 1996 to a peak of $546 million in 2013), GM corn (from $3.2 million in 1997 to a peak of $143 million in 2012 and down to $107 million in 2013), and GM soybean (from $41,000 in 1997 to a peak in 2006 of $18 million and down to $7 million in 2013) (Brookes and Barfoot, 2015); however, there has been a general stagnation in net farm from 1976 to 2015 despite an increase in gross income (see Statistics Canada, 2016b). In addition, there has been an exponential rise in farm expenses and farm debt (see Statistics Canada, 2016a, 2016d). The impact of adopting GM crops on farm income is attributed to additional factors such as: global and domestic commodity prices, currency exchange fluctuations, and trade decisions; the profitability of a crop in terms of how much any benefits outweigh the cost of inputs such as seeds, pesticides, fertilizers, fuel, and land;

farm management and agronomic practices; and geographical location and environmental attributes affect profitability directly through increased fertility and indirectly through its influence on pests.

Lastly, despite stagnant net farm income and increasing farm expenses and debt, the net income of multinational GM seed and agrochemical corporations continue to rise at unprecedented rates. For example, Monsanto's average annual net income from 2005 to 2015 has increased from a net income of US$255 million in 2006 to US$2.3 billion in 2015 (Monsanto, 2007, 2010, 2013, 2016b). To put this in perspective, Monsanto's (2014a) and DuPont's (2014a) net income in 2013 exceeded the net income of approximately 205,000 farmers in Canada.

The restructuring of agriculture and the agro-food system stems from an extension of the structural crisis of global capitalism, which varies in form and intensity, according to natural qualities and social and technological characteristics at national and international scales. Agricultural restructuring in Canada has brought significant challenges to the mostly family-owned farms in Canada. This has included an increase in off-farm mechanical (e.g., machinery) and biological (e.g., GM seeds and associated agrochemicals) inputs, farm production that is increasingly focused on fewer and larger farms in the most productive regions, large capital-intensive farms that focus on fewer farm products as resources are devoted to those items giving the best comparative advantage, a decrease in farm subsidies, government agricultural policy shifts that favour the private sector, and unfavourable environmental and market conditions. Among the purported solutions to these perplexing issues has been intense innovation in agricultural biotechnology, funded by the Government of Canada and multinational corporations, aimed at economic growth and the expansion of value accumulation in an era of competitive innovation in high-technology industries. This is manifested in the rise and consolidation of a handful of multinational GM seed and agrochemical corporations, vigorous marketing and government regulatory approval of GM products, the appropriation of germplasm, rapid expansion of IP rights, and the high adoption and production of GM crops. Farmers are increasingly dependent on commodified (GM) seeds, which have been rapidly converted from public goods and means of production controlled by direct producers, into commodities controlled by multinational corporations, bought and sold in trans-national markets. The serious consequences for farmers have included a significant increase in the cost of GM seeds and associated agrochemicals relative to other operational costs; GM seeds that are less adapted to their regions and less resilient to environmental change; fewer choices for farmers as conventional seeds are phased out; and less farmer autonomy due to stringent contracts that prevent farmers from selecting, saving, exchanging, selling, and reusing seeds. Although there has been a rise in yields and gross farm income as a result of adopting GM crops, net farm income has remained stagnant due to an increase in farm expenses and debt while the net income of leading GM seed and agrochemical corporations has increased sharply as farmers become more dependent on commodified off-farm inputs that are increasingly controlled by multinational agribusiness corporations. These processes constitute a major driving force behind the restructuring and transformation of the Canadian agriculture and agro-food system.

2.5 Conclusion

Having examined the academic literature on agricultural geography and agricultural biotechnology and identified some gaps, I provided an alternative theoretical framework for understanding the development of science and (bio) technology. I begin by identifying the concepts from Marx that underlie the critical role of science and technology in capitalism. The contradiction between the productive forces and the social relations of production which accounts for the historical development of a succession of modes of production is applied to understand the dynamics of capitalism. Marx incorporated his conceptualization of technology by way of the abstract concepts productive forces and social relations of production as these are embodied in the concrete materiality of the labour process, while abstracting from the specific details of actual technological changes. The on-going quest on the part of capitalists to appropriate surplus-value impels perpetual revolutions in the productive forces (i.e., the means of production such as mechanical implements including tools and machinery and biological implements including GM seeds and agrochemicals, raw materials, and spaces; and labour-power in its various qualitative aspects). Such revolutions, however, create conditions that are inconsistent with the further accumulation of capital and the reproduction of class relations. This results in an unstable and crisis prone capitalist system, though each crisis may be resolved through a restructuring of the productive forces and social relations of production, the underlying source of conflict is never eliminated.

Capitalist society has exhibited an extraordinary degree of technical change and organizational dynamism. Competition compels capitalists to constantly attempt to lower the costs of production to earn the profits necessary for the accumulation of capital that ensures their survival. To do so and increase the value they appropriate, capitalists try to increase the length and intensity of the workday, lower wages, and increase the productivity of labour through technological development. Technological development implies using less labour for the same or more output. The coercion on individual capitalists to accumulate operates through the mechanism of competition. These factors play a central role in the interrelationship between capitalism and technical change.

Technical change occurs during specific historical periods characterized by long cycles in the uneven development of capitalism. Here, "The periodic recurrence of minor cycles is conditioned by the internal dynamics of capitalist forces, and manifests itself always and everywhere once the market comes into existence. As regards the large segments of the capitalist curve of development (fifty years)… their character and duration are determined not by the internal interplay of capitalist forces but by those external conditions through whose channel capitalist development flows" (Trotsky, 1973, 276-277). 'External conditions' and the relative autonomy of 'superstructural' phenomena determine the uneven flow of capitalist development that incorporates perpetual revolutions in technology.

Invention and innovation occur in clusters of 'creative destruction'. New technologies displace pre-existing technologies in an attempt to transcend constraints on economic development. This occurs at the micro (innovation and learning behavior in the firm), meso (innovation-driven industry dynamics), and macro (innovation-driven economic growth and competiveness) levels of the economy. Micro processes include cognitive acts that identify the inputs that are to be acted on and any required equipment, and physical acts that specify the actions that need to be taken to achieve a desired outcome. These are embedded in procedures and organizational routines that draw on specific elements of knowledge ranging from 'theoretical' or codified knowledge (general scientific knowledge to knowledge of highly specific engineering applications) to 'know-how' or tacit knowledge reflected in the procedures and organizational routines of those engaged in production.

At the meso and macro levels, newly introduced radical innovations that make it to the market are subjected to a series of incremental innovations. Changes generally occur slowly at first, while producers, designers, distributors and consumers engage in feedback learning processes; rapidly and intensively once a dominant design has become established in the market; and slowly once again when maturity is reached. In addition, technological paradigms and trajectories attempt to capture the common features of technological activities and the procedures and direction of technical change. What holds for the technological paradigms and trajectories of individual technologies also holds in terms of the evolution of whole products in an industry and whole sets of interrelated industries referred to as technology systems. Just as individual innovations are interconnected in technology systems, these are in turn interconnected in technological revolutions. A technological revolution can be defined as "a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems" (Perez, 2010, 189). The structure of each revolution includes a significant number of interrelated new products and production technologies, giving rise to new industries. As a result, techno-economic paradigm is articulated through the use of new technologies as they diffuse and multiply their impact across the economy and eventually also modifies the way socio-institutional structures are organized.

Technical change is fragmented into discrete geographical locations. The geographical implications of long cycles in the uneven development of capitalism are profound and may be associated with the rise and fall of regions and places of production. A regional economy may be crudely conceived as a collection of economic agents, firms, and workers embedded in a set of organizational and institutional structures that guide behavior to a greater or lesser degree. Regions are also repositories of accumulated knowledge, both codified and tacit. Regional innovation systems incorporate learning regions, and localized knowledge economies that foster the production of knowledge. Different knowledge economies/learning regions produce different subsets of knowledge as the source of their competitive advantage. The regional innovation system can be thought of as the institutional infrastructure supporting innovation in the production structure of a region. The systemic dimension of the regional innovation system derives in part from the team-like character associated with innovation in networks. The innovation process of firms is also strongly shaped by their specific knowledge-base, which tends to vary systematically by industrial sector. The knowledge-base may be distinguished between two types: analytical and synthetic. These types entail different mixes of tacit and codified knowledge, as well as different codification possibilities and limits. They also imply different qualifications and skills, reliance on different organizations and institutions, as well as contrasting innovation challenges and pressures.

The contributions on the development of science and technology in capitalism provide the context for understanding the historical and geographical development of agricultural biotechnology and the adoption and production of GM crops. The development of agricultural biotechnology is not simply the result of the autonomous processes of a purely technological phenomenon (i.e., the so-called 'biotechnology revolution'), but capitalist social relations that demand innovation manifested in the emergence of agricultural biotechnology. This has been the result of the efforts of a conjunction of social actors (e.g., governments, corporations, and public institutions) and practices of scientific research and technological applications necessary for sustaining such processes amidst systemic contradictions. The outcome has been a R&D structure that broadly accommodates the needs of capital and promotes the patenting of life forms in agriculture, further concentration and centralization among multinational GM seed and agrochemical corporations, a discourse that sustains and legitimizes the production of GM crops by positioning agricultural biotechnology as a panacea for perplexing socio-economic problems such as (inter) national economic growth and development, a stagnate agricultural industry, health and environmental issues, population growth and poverty, and so on, and the unprecedented global adoption and production of GM crops.

The Canadian case shows that the adoption and production of GM crops represents in part a significant attempt by the state to secure the ongoing capitalist development of the agricultural biotechnology industry. This occurs through a complex array of processes, on the one hand, by a variety of government agencies that are necessary for the procurement of costly generic scientific and technological R&D,

legislation, and regulation (e.g., Canadian Food Inspection Agency, Environment Canada, Health Canada, Fisheries and Oceans Canada), and on the other hand, by instances of the state neutralizing or countering the political struggles waged by various civil society organizations that have challenged such outcomes. This signifies an economic geography in which 'competitiveness' at the national and international scales is heralded resulting in the support of innovation systems and the expansion and protection of value accumulation, while simultaneously civil society action seeks to challenge pressures toward market-oriented restructuring and reform. The GM crops narrative is in part about the tension between compliant government structures and resistant civil society action seeking to partially counter the encroachment of the capitalist market.

In addition, the state and sections of civil society, government scientists and bureaucrats, corporations, and industry supported websites and NGOs have played an important role in the construction of a pro-GM crops discourse. The manipulation of the pro-GM crops discourse serves to control the discursive norms and institutional contexts that surround agricultural biotechnology. This process seeks to represent the interest of capitalist accumulation and those of individual capitals as the general interests of the Canadian public and farming communities therefore establishing and maintaining some of the conditions that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

Lastly, the restructuring of the agricultural sector has encompassed a wide range of forces and conditions among which has been the dramatic increase in the adoption and production of GM crops. This has been associated with the rise and consolidation of a handful of multinational GM seed and agrochemical corporations aimed at economic growth in the agricultural sector in an era of competitive innovation in high-technology industries. The serious consequences for Canadian farmers have included stagnant net farm income despite increasing yields and gross income, higher farm expenses and debt, and stringent patent laws that limit farmers' autonomy.

Chapter Three

Historical and Geographical Macro-Empirical Analysis of Agricultural Biotechnology

3.1 Introduction

Historically farmers have been the primary generators and stewards of crop genetic resources. The common heritage principal of genetic resources as belonging to the public domain has been the foundation of farming communities for millennia where seeds were exchanged and invention was collective. The planting of genetically diverse and geographically localized landraces by farmers may be conceptualized as a decentralized management regime with significant biological, political, and economic implications (Castree, 2008; Shiva, 2007; Stone, 2007). Studies of traditional farming systems suggest that farmers in Africa (Mulatu and Zelleke, 2002; van Leur and Gebre, 2003) the Americas (Bellon et al., 1997) and Asia (Jaradat et al., 2004) managed and continue to manage existing varieties and innovate new ones through different techniques including hybridization with wild species, regulation of cross-pollination, and directional selection. In many parts of the world it is women's knowledge systems that select and shape crop genetic resources (Beintema, 2014).

Over the past century, however, plant breeding has developed incrementally by harnessing advances in plant biology, supplemented at times by traditional empirical knowledge (lore), and informed by the principles of Mendelian genetics. The scientific breakthrough that figured most prominently in the subsequent commodification of biotechnology was that of Herbert Boyer and Stanley Cohen. In 1973, Boyer and Cohen employed genetic engineering techniques to transfer genetic material into a bacterium allowing the imported material to be reproduced. In 1976, Boyer joined venture capitalist Robert Swanson and founded one of the first biotechnology companies Genentech. In 1978, Genentech cloned human insulin using recombinant technology and bacteria (Thieman and Palladino, 2012). The rapid expansion of the biotechnology industry quickly followed as investment dollars poured into the industry. Peekhaus (2013, 39) noted, “Aside from a plethora of start-up biotechnology companies, a number of the major pharmaceutical and chemical multinationals began developing in-house research programs using recombinant DNA, signed research contracts with some of the start-ups, and even began acquiring equity stakes in a number of them”.

The purpose of this chapter is to examine the historical and geographical development of agricultural biotechnology and the adoption and production of GM crops. I address the following questions: what role have public and private institutions played in the development of agricultural biotechnology? How did changes in IP rights affect access to and use of genetic resources? How has public and private investment in agricultural R&D affected the development of GM crops? What are the effects of greater concentration and centralization among GM seed and agrochemical corporations? To what extent have GM crops been adopted and produced globally? I argue that the historical and geographical development, adoption, and production of GM crops is not simply the result of the autonomous processes of a purely technological phenomenon (i.e., the so-called ‘biotechnology revolution’), but capitalist social relations that demand innovation manifested in the emergence of agricultural biotechnology. This has been the result of the efforts of a conjunction of social actors (e.g., governments, corporations, and public institutions) and practices of scientific research and technological applications necessary for sustaining such processes amidst systemic contradictions. The outcome has been a R&D structure that broadly accommodates the needs of capital by promoting the patenting of life forms in agriculture, further concentration and centralization among multinational GM seed and agrochemical corporations, and the unprecedented global adoption and production of GM crops.

The chapter is organized in the following way. In section **3.2 The Emergence of Agricultural Biotechnology** I examine the shift from public to private ownership of germplasm (section ***3.2.1 From Public to Private Ownership of Germplasm***); the ensuing IP rights in plant genetic resources (section ***3.2.2 Intellectual Property Rights in Plant Genetic Resources***); the investments in agricultural R&D (section ***3.2.3 Agricultural Research and Development Investment***); and the increasing concentration and centralization of GM seed and agrochemical corporations (section ***3.2.4 Concentration and Centralization in the Agricultural Biotechnology Industry***). In section **3.3 The Global Adoption of GM Crops** I explore the number of GM crops field trials conducted (section ***3.3.1 GM Crop Field Trials***); the adoption of GM crops by country and crop (section ***3.3.2 GM Crops by Country and Crop***); the economic impacts of adopting GM crops (section ***3.3.3 Economic Impacts of Adopting GM Crops***); and the specific cases of the US and Canada (section ***3.3.4 US Leads and Canada Follows***). In section **3.4 Conclusion** I provide a summary of the findings and draw out some conceptual implications and the contribution of the chapter to the academic literature.

3.2 The Emergence of Agricultural Biotechnology

3.2.1 From Public to Private Ownership of Germplasm

In the first half of the 20th century, public sector institutions emerged that catalyzed formal crop improvement, focusing on yield with high input requirements and wide adaptability. These advancements had both positive and negative impacts on farming communities as more uniform crops replaced locally adapted crops. Expeditions to collect global germplasm by several countries and gene banks were established for the conservation of germplasm for use in research and breeding. Public sector institutions were the dominant distributors of improved varieties. The rediscovery of Mendel's laws of heredity in 1900 and the discovery of heterosis in 1908 spurred the growth of the commercial industry (Crow, 1998). Throughout the 20th century, universities and research institutes gradually specialized in basic research while the private sector increased its capacity in practical breeding. The public sector assumed primary responsibility for managing genetic resources, creating scientific networks that acted as conduits of information and technology flow, and establishing regulatory bodies for variety testing, official release, and seed certification (Pingali and Traxler, 2002).

The education, research, and institutional system triad commonly found in developed countries was exported to developing countries in an attempt at fostering agricultural development and food security mainly through the development of broadly adapted germplasm. With the aid of the Rockefeller Foundation (and later the Ford Foundation), a collaborative research program on maize, wheat, and beans in Mexico was founded in 1943. This laid the foundation for the first international research centers of the CGIAR, with the initial focus to improve globally important staple crops. The formation of the CGIAR centers laid the groundwork for the emergence of the Green Revolution technologies. Borrowing from breeding work in developed countries, high-yielding varieties of rice, wheat, and maize were developed in the 1960s and 1970s. Also, the FAO launched a significant program to establish formal seed production capacities and 'lateral spread' systems in developing countries to make the new varieties available to as many farmers as possible. These public seed projects, financed by the UNDP, World Bank, and bilateral donors were subsequently commercialized, often as parastatal companies before national or multinational seed companies were established in developing countries (IAASTD, 2009). The CGIAR and the FAO arrangements, however, had limitations. Formal breeding programs have resulted in homogeneous varieties that favour uniform conditions rather than the heterogeneous ecological clines that characterize the majority of small farmers' fields. The prevalence of pests, disease, and variability of climate and land require a wide range of locally adapted heterogeneous varieties (Wolfe, 1992). Erosion of crop diversity is commonly paralleled by erosion of farmers' skills and empowerment. This results in a loss of community sovereignty as fewer people are able to cultivate and control their own food (Stone, 2007). Debates continue as to whether or not increases in food production, such as those of the Green Revolution, necessarily lead to increases in food security (Das, 2002).

3.2.2 Intellectual Property Rights in Plant Genetic Resources

Until the 1970s, there were very few national and international laws creating proprietary rights or other forms of explicit restriction of access to plant genetic resources. Since that time, however, the common heritage principle has been turned on its head, with the gradual encroachment of claims for control over access to and use of genetic resources through the introduction of IP laws (Safrin, 2004). As a result, the GM seed industry has benefited from the ability to appropriate profits through end-point royalties and excluding others from making, using, importing, and selling patented GM seeds for a set period of time, usually between fifteen and twenty years. This has allowed GM seed companies to recoup investments and foster further research, organizational capability, and growth. The increasingly international character of IP laws regimes is a reflection of widespread and integrated trade in germplasm resources as well as global trends toward liberalization of markets and trade, privatization, and structural adjustment that reduce the role of the public sector (Tripp and Byerlee, 2000).

In the 1980s, patents entered plant breeding initially through court decisions in the US via association with biotechnology. In particular, the influential 1980 Supreme Court decision in Diamond vs. Chakrabarty laid the legal groundwork for the privatization and commodification of germplasm and established the US as the global patent leader (Stein, 2005). Subsequently, other developed countries offered greater protection to a wider array of products and processes, such as genes, traits, molecular constructs, and enabling technologies (Lesser and Mutschler, 2002). The EU, however, introduced a breeders' exemption into its IP laws, and some EU countries introduced a farmers' privilege to avoid the pitfalls of excessively strong protection (World Bank, 2006). The series of biotechnology patenting cases that followed during the 1980s and 1990s not only greatly expanded the legal boundaries of patentable living matter, but also narrowed the traditional seed saving exemptions for farmers (Stein, 2005). This loss of privilege generated heated debates among countries because it limits the rights of farmers to freely save, exchange, reuse, and sell agricultural seeds (Tansey and Rajotte, 2008). In addition, The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization, devised in 1994 by the US in conjunction with the private sector extended the global reach of IP regulation based on the concepts of protection and exclusion rather than dissemination and competition. Unlike earlier conventions, TRIPS does not merely circumscribe the range of acceptable policies, but obliges governments to take action to protect IP rights (Sell, 2003).

As pressure to protect IP rights in improved varieties and 'inventions' increased, the atmosphere concerning access to and use of genetic resources became politicized. This was augmented with concern, particularly among developing countries, that inequitable global patterns were established in the distribution of benefits associated with the use of genetic resources. Concurrently, there was growing concern that genetic diversity and local knowledge related to the use of those resources continued to be eroded under the pressures of modernization (Gepts, 2004). In response, the international community attempted to address these tensions by creating a new regime for access to genetic resources and sharing the benefits associated with their use. One of the most significant outcomes was the Convention on Biological Diversity (CBD) which came into force in 1993. The CBD emphasized states' sovereign rights over their natural resources and addressed the rights of local and indigenous communities in this respect. Most countries have interpreted the access and benefit sharing provisions of the CBD as the basis for establishing much tighter procedural and substantive restrictions to gaining access to genetic resources within their borders (IAASTD, 2009).

3.2.3 Agricultural Research and Development Investment

Investment in agricultural R&D in the public and private sectors is a significant factor affecting the development of GM crops. The full scope of public sector agricultural R&D covers three main areas: crops, livestock, and natural resources with more than half of agricultural R&D investment allocated for the development of crop technologies. Public sector agricultural R&D in the US and Canada is conducted mainly in state agricultural experiment stations located in colleges and universities with agricultural programs and in federally administered, but often regionally located, laboratories. In Asia-Pacific and Latin America approximately 75% of the public sector agricultural R&D is conducted by government agencies. This is similar to the government agency share in 27 countries in sub-Saharan Africa. A small but growing proportion of public sector agricultural R&D in Latin America and sub-Saharan Africa is conducted by non-profit institutions. Non-profit institutions are often managed by independent boards not directly under government control. Many are closely linked to producer organizations from which they receive the large majority of their funding, typically by way of taxes levied on production or exports (IAASTD, 2009).

Global public sector agricultural R&D investment increased by 22% during the 2000-2008 period, from US$26.1 to US$31.7 billion, an average of 2.4% increase per annum. Expenditures were split roughly evenly between developed (high-income) and developing (middle-income and low-income) countries. Middle-income countries such as China, India, and Brazil accounted for approximately 25% of global investment and approximately 50% of combined investment in middle-income and low-income countries. Other middle-income countries (Argentina, Brazil, Iran, Nigeria, and Russia) also significantly increased their public sector agricultural R&D investment and collectively accounted for $1.2 billion or 20% of global investment (Beintema et al., 2012). In low-income countries, investment increased by 2.1 % per year during the 2000-2008 period, driven largely by increases in the larger East African countries (Ethiopia, Kenya, Tanzania, and Uganda) (Beintema and Stads, 2011). Comparing public sector agricultural R&D investment across middle-income and low-income regions reveals that all regions increased their agricultural R&D expenditures from 2000 to 2008. Within regions, however, this was mostly driven by a few countries. China and India accounted for more than 90% of investment in Asia-Pacific. Likewise, approximately 50% of the investment in sub-Saharan Africa was driven by Nigeria, and approximately 33% was driven by Ghana, Tanzania, and Uganda. Argentina, Brazil, and Mexico accounted for 86% of Latin America's investment. Iran and Turkey accounted for 75% of investment in West Asia and North Africa. Among the former Soviet States and Eastern Europe, Russia accounted for approximately 50% of investment (Beintema et al., 2012).

High-income countries were an exception to the global pattern. Public sector agricultural R&D investment in high-income countries has continued to decrease. In the 1980s, investment averaged 2% per annum, but decreased to an average of 1.1% per annum from 2000 to 2004, and further to an average of approximately 0% from 2005 to 2008. The US and Japan, with investment levels of US$4.8 and US$2.7 billion in 2008 respectively, accounted for 50% of public sector agricultural R&D investment among high-income countries from 2000 to 2008 (Fuglie and Schimmelpfennig, 2010).

Global private sector investment in agricultural R&D increased from US$12.9 billion in 1994 to US$18.2 billion in 2008. Information on private sector investment in developing countries is limited, but some authors suggest significant growth in large middle-income countries. Private sector agricultural R&D investment in India accounted for 19% of total investment from 2008 to 2009 (Pal et al., 2012). In China, private sector investment accounted for 16% of total investment in 2006 (Hu et al., 2007). Examining low-income countries in sub-Saharan Africa, only 2% of total agricultural R&D is conducted by the private-sector, most of which was conducted in South Africa. Most firms in sub-Saharan Africa have few research staff with low total investment, focusing mainly on crop improvement research (Beintema and Stads, 2011).

Although the vast majority of private sector agricultural R&D investment occurs in developed countries, many of these firms maintain experiment stations in developing countries in order to transfer new proprietary technologies to those markets (Fuglie et al., 2011). Private sector investment in agricultural R&D in developed countries differs from one country to another. In 2000, more than 80% of the total agricultural R&D investment in Belgium, Sweden, and Switzerland was conducted by the private sector. In contrast, private sector shares were below 25% in Australia, Austria, Iceland, and Portugal that same year (Fuglie and Schimmelpfennig, 2010). Private sector agricultural R&D investment in the GM seed industry has increased rapidly both in absolute terms and relative to public expenditures, altering the focus of R&D and of the crops studied. Technological innovation in the form of modern biotechnology and changes in IP rights have enabled private sector firms to capture more value from the GM seeds that they develop, and GM seed R&D remains the most intensive of the agricultural input sectors to date (Fernandez-Cornejo et al., 2014).

One of the most rapidly growing areas of private sector R&D expenditure has been in biotechnology. According to the OECD (2015), biotechnology R&D expenditure in 2013 or latest available year totaled $US42.6 billion for 28 countries, with developed countries accounting for the vast majority of biotechnology R&D expenditure. In particular, the US share of biotechnology R&D expenditure in 2013 was $US26.9 billion accounting for 63% of the total biotechnology R&D expenditure (see Table 3.1).

Table 3.1: Private Sector Biotechnology Expenditure in 2013 or Latest Available Year

Country	**Millions of $US, 2013 or latest available year**	**Biotechnology Expenditure as Percentage of Global Biotechnology Expenditure**
United States	26893.0	63.20
France	3267.9	7.68
Switzerland	2560.0	6.02
Korea	1354.4	3.18
Japan	1230.1	2.89
Germany	1201.8	2.82
Denmark	1082.2	2.54
Spain	756.6	1.78
Belgium	660.8	1.55
Netherlands	420.2	0.99
Sweden	411.7	0.97
Israel	400.5	0.94
Italy	395.3	0.93
Ireland	380.9	0.90
Canada	308.4	0.72
Austria	159.7	0.38
Czech Republic	140.6	0.33
Norway	137.2	0.32
Russian Federation	135.3	0.32
Australia	120.5	0.28
Finland	111.3	0.26

Poland	104.7	0.25
Mexico	93.9	0.22
South Africa	69.6	0.16
Slovenia	69.3	0.16
Portugal	41.8	0.10
Estonia	33.3	0.08
Slovak Republic	10.5	0.02

Source: OECD, 2015

3.2.4 Concentration and Centralization in the Agricultural Biotechnology Industry

In the context of newly emerging IP rights and the development of biotechnology there has been greater concentration and centralization among GM seed and agrochemical corporations. Concentration in the chemical industry began with the development of chemical firms into multinational corporations. This is best illustrated by the emergence of DuPont from its humble beginnings in the early 1800s to its current position as a leading multinational GM seed and agrochemical corporation (see DuPont, 2015). Centralization followed as multinational chemical corporations began to acquire family-owned seed companies to capitalize on the synergies between chemical and seed inputs (Falcon and Fowler, 2002). These processes intensified throughout the 1990s as a result of extreme vertical integration of the seed and biotechnology industries followed by a horizontal integration of the agriculture and pharmaceutical industries into life sciences companies (Hayenga, 1998). A handful of vertically coordinated firms have been the key players in ushering in the biotechnology revolution in agriculture in the US and other countries. Agrochemical corporations, such as Monsanto and Syngenta, which had no expertise in either biotechnology or plant breeding, began to massively invest in developing GM varieties by recruiting new staff and merging with or acquiring seed companies that had experience in plant breeding and the commercialization of seeds. Between 1995 and 1998, approximately 68 seed companies in the US were either acquired by or entered into joint ventures with the top six multinational corporations (King, 2001).

Vertical integration has been driven by: (1) the stagnation of the agrochemical sector; (2) the changing knowledge base and innovations in chemistry and biotechnology; and (3) the policy environment, such as increased regulations (Falcon and Fowler, 2002; Hayenga, 1998). Srinivasan's (2004) analysis of thirty countries identified a high degree of concentration in the ownership of plant variety rights for six major crops at the national level in the developed world. Liberalized foreign investment policies and multinational structures have allowed agribusiness companies to conduct upstream research with local seed companies providing the crop varieties developed for specific geographical markets. For developing countries, this concentration has implications for (1) the structure and autonomy of their domestic seed industries; (2) their access to protected varieties; and (3) the use of important breeding technologies.

The outcome of the increasing concentration and centralization in the agricultural biotechnology industry has had mixed social, economic, and environmental effects in both developed and developing countries, with the differences caused in part by the technology adopted, the structure of farming, the organization of GM seed markets, and the regulatory and institutional contexts (Fukuda-Parr, 2007). For example, agricultural liberalization in East Africa has led to an increase in the number of seed companies and varieties on the market, but this has not led to an increase of maize yields or production per capita since the mid-1980s (De Groote et al., 2005). Also, the top 10 agribusiness companies based in the US, Europe, and Japan and representing half of the world's commercial seed sales increased their control of biotechnology patents to over 50% in 2000 (Pray et al., 2005). Some authors have suggested that we are seeing the beginning of the negative impacts on innovation and competition through increased concentration and centralization in the private sector (Brennan et al., 2005). This may be illustrated by the decreasing trend in the number of granted plant technology patents in the US from 2002 to 2015 (see Figure 3.1).

Figure 3.1: Number of Plant Technology Patents Granted in the US

Source: USPTO, 2016

Given greater concentration and centralization in the agricultural biotechnology industry, a handful of multinational corporations have emerged as the global leaders (See Table 3.2).

Table 3.2: Top 12 GM Seed and Agrochemical Corporations by Country

Country	**Corporation**
Denmark	DLF-Trifolium
France	Groupe Limagrain
Germany	BASF, Bayer, KWS SAAT SE
Japan	Sakata, Takii
Switzerland	Syngenta
US	Dow, DuPont, Land O'Lakes, Monsanto

BASF is based in Ludwigshafen, Germany and is organized into five segments: chemicals, performance products, functional materials, agriculture, and oil and gas. Since 2007, BASF Plant Science has collaborated with Monsanto in plant biotechnology focusing on development of high-yielding and stress-tolerant crops. BASF Crop Protection started research in nitrogen management, water management, and biological crop protection, announcing the formation of Functional Crop Care in 2011. With the 2012 acquisition of Becker Underwood, BASF established Functional Crop Care as a global business unit to become a leading global provider of biological seed treatment and enhancement, and biological crop protection products. The company has approximately 113,000 employees globally including approximately 10,700 in R&D. Research is conducted with more than 600 universities, research institutes, and companies globally including approximately 3000 research projects. In 2014, BASF R&D expenditure was approximately USD$2.1 billion with 27% or USD$575.1 million allocated to plant biotechnology. Reported sales in 2014 were approximately USD$8.3 billion with 7% or USD$581 million in agriculture. Net income in 2014 was approximately USD$5.8 billion (BASF, 2015).

Bayer is a global firm based in Leverkusen, Germany with core competencies in the areas of health care, agriculture, and high-tech polymer materials. Bayer Crop Science is organized in two operating segments: Crop Protection Seeds and Environmental Science. Crop Protection/Seeds markets a portfolio of high-value GM seeds and traits along with chemical and biological pest management solutions, at the same time providing extensive customer service to the agriculture industry. Environmental Science focuses on non-agricultural applications, with a broad portfolio of pest control products and services for areas ranging from the home and garden sector to forestry. Bayer collaborates with universities, public research institutes, and partner companies (e.g., MS Technologies, Syngenta). The company has approximately 119,000 employees globally including approximately 14,000 in R&D. At the end of 2014, Bayer owned approximately 68,200 valid patent applications and patents globally relating to some 8,300 protected inventions. In 2014, Bayer R&D expenditure was approximately USD$4 billion with 25% or USD$1 billion allocated to Bayer Crop Science. Reported sales in 2014 were approximately USD$47.4 billion with 22% or USD$10.4 billion in Bayer Crop Science. Net income in 2014 was approximately USD$2.8 billion (Bayer, 2015).

Dow is based in Michigan, US specializing in chemical, advanced materials, agro-sciences, and plastics. The Agricultural Sciences segment provides crop protection and GM seed and plant biotechnology products and technologies, urban pest management, and healthy oils. The business invents, develops, manufactures and markets products for use in agricultural, industrial, and commercial pest management, and food service. Agricultural Sciences has significant technology-driven growth, led by plant biotechnology traits and crop protection products that utilize proprietary formulations. As a result, patents, trademarks, licenses, and registrations are used to protect investment in germplasm, traits, and proprietary chemistries and formulations. Dow also licenses plant biotechnology traits from third parties and engages in research collaborations with global industry, universities, and governments. The company has approximately 53,000 employees globally. Dow owns 4,210 active US patents and 17,311 active foreign patents with 855 in Agricultural Science. In 2014, Dow R&D

expenditure was approximately USD$1.6 billion. Reported sales in 2014 were approximately USD$58.2 billion with 13% or USD$7.3 billion in Agricultural Science. Net income in 2014 was approximately USD$3.4 billion (Dow, 2015).

DuPont is based in Delaware, US and consists of 12 businesses which are aggregated into seven segments in agriculture, electronics and communications, industrial biosciences, nutrition and health, performance chemicals, performance materials, and safety and protection. Agriculture businesses, DuPont Pioneer and DuPont Crop Protection, deliver products and services that are specifically targeted to achieve gains in crop yields and productivity, including Pioneer brand GM seed products and well-established brands of insecticides, fungicides, and herbicides. The company has approximately 63,000 employees globally. DuPont owns more than 27,000 patents and 16,500 patent applications. In 2014, Dow R&D expenditure was approximately USD$2 billion with 50% or USD$1 billion allocated to agriculture. Reported sales in 2014 were approximately USD$34.7 billion with 33% or USD$11.3 billion in agriculture. Net income in 2014 was approximately USD$3.6 billion (DuPont, 2015).

Monsanto is based in Missouri, US and is a global provider of agricultural products for farmers such as GM seeds, biotechnology traits, herbicides, and precision agriculture products. The company is organized in two segments: genomics and agricultural productivity. The GM seeds and genomics segment produces leading GM seed brands, including DEKALB, Asgrow, Deltapine, Seminis, and De Ruiter, and develops biotechnology traits that assist farmers in controlling insects and weeds. Monsanto also provides other GM seed companies with genetic material for their GM seed brands. The company has approximately 27,000 employees globally. In 2014, Monsanto R&D expenditure was approximately USD$1.7 billion. Reported sales in 2014 were approximately USD$15.9 billion. Net income in 2014 was approximately USD$2.7 billion (Monsanto, 2015a).

Syngenta is based in Basel, Switzerland and is an agriculture company with businesses producing herbicides, insecticides, and fungicides for crop protection, field crops, vegetables and flower seeds, seed care products, turf, garden, home care, and public health products. The company has a 141 R&D facilities in Switzerland, UK, US, China, and India. The company has approximately 29,000 employees globally. In 2014, Syngenta R&D expenditure was approximately USD$1.4 billion. Reported sales in 2014 were approximately USD$15.1 billion. Net income in 2014 was approximately USD$1.8 billion (Syngenta, 2015). The total investment in agricultural biotechnology R&D by the leading firms in 2014 was approximately USD$7.3 billion, with total sales of approximately USD$60.6 billion, and net income of USD$20.1 billion.

In 1996, the top 11 GM seed companies (Monsanto, DuPont, Syngenta, Groupe Limagrain, Land O'Lakes, KWS SAAT SE, Dow, Sakata, DLF-Trifolium, Takii) accounted for 37% of the world's GM seed market. In 2009, the top three GM seed companies in the world (Monsanto, DuPont, and Syngenta) accounted for 23%, 14%, and 8% respectively totaling 45% of the global proprietary GM seed market, and GM seed revenues of approximately US$7.3 billion, US$4.6 billion, and US$2.5 billion respectively totaling US$14.4 billion. Monsanto, which emerged as the largest player in the industry, controlled 23% of the global proprietary GM seed market, and an estimated 87% of the total land area planted with GM seeds was planted with Monsanto products either directly or indirectly through licences to other companies. In terms of proprietary GM seed revenues, in 2009 sales for the top 11 companies were: US$19.7 billion (62%) of the US$32 billion global proprietary seed market, and the top three companies controlled US$14.5 billion (45%). Monsanto controlled US$7.3 billion (23%) of the US$32 billion global proprietary GM seed market (Peekhaus, 2013, 42-44). As of 2013, the world's top three GM seed companies, Monsanto, DuPont, and Syngenta accounted for 26%, 21%, and 8% respectively or 55% collectively of the global proprietary GM seed market, while the top three agrochemical companies, Syngenta, Bayer, and BASF accounted for 20%, 18%, and 13% respectively or 51% collectively of the global agrochemical market. Collectively, the top six companies: Monsanto, DuPont, Syngenta, Bayer, Dow, and BASF accounted for 65% of the global proprietary GM seed market, and 75% of the global agrochemical market with sales of GM seeds, agrochemicals, and GM traits exceeding $65 billion per annum (ETC Group, 2015).

3.3 The Global Adoption of GM Crops

3.3.1 GM Crop Field Trials

While the rapid adoption and production of GM crops is the fulfillment of R&D efforts, benchmarks include the number of GM crop field trials. GM crop field trials are an important indicator of the global adoption of agricultural biotechnology. These trials are an essential early step in bringing agricultural biotechnology to commercial markets. From 1986 to 1995, a total of 3,647 field trials were conducted in 34 countries (see Table 3.3).

Table 3.3: Global Number of GM Crop Field Trials by Country from 1986 to 1995

Country	**Number of field trials**
Argentina	78
Australia	46
Belgium	97
Belize	5
Bolivia	6
Bulgaria	3
Canada	486
Chile	39
China	60
Costa Rica	17
Cuba	18
Denmark	16
Egypt	2
Finland	10
France	253
Germany	49
Guatemala	3
Hungary	22
Italy	69
Japan	25
Mexico	38
New Zealand	15
Norway	1
Portugal	5
Russia	11
South Africa	22
Spain	30
Sweden	18
Switzerland	2
Thailand	2
The Netherlands	113
United Kingdom	133
United States	1,952
Zimbabwe	1
Total	**3,647**

Source: James and Krattiger, 1996

By 2000, more than 11,000 field trials were conducted using 81 GM crops (see Table 3.4).

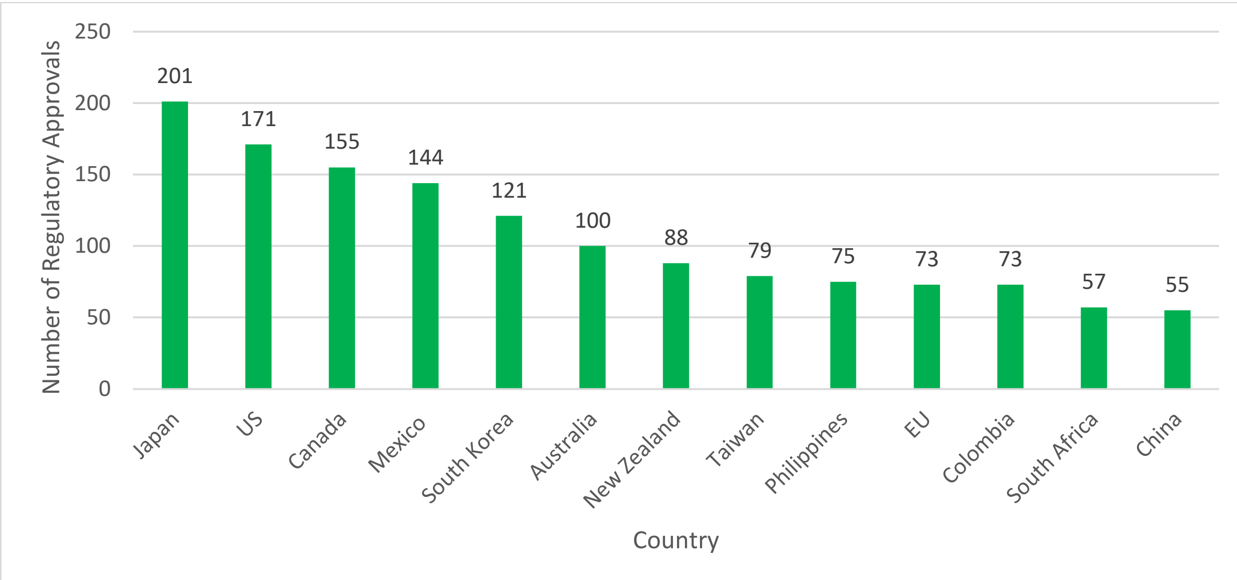
Table 3.4: GM Crop Field Trials by Crop and Region from 1986 to 2000

GM crop	US and Canada	Europe, Australia, New Zealand, and Japan	Developing Countries	Total
Corn	2749	452	680	**3881**
Canola	826	366	50	**1242**
Potato	770	227	91	**1088**
Soybean	552	20	210	**782**
Cotton	407	72	244	**723**
Tomato	494	89	71	**654**
Sugar beet	118	237	39	**394**
Tobacco	197	63	53	**313**
Wheat	190	23	19	**232**
Rice	102	36	51	**189**
Other	1087	316	207	**1610**
Total	**7492**	**1901**	**1715**	**11108**

Source: Pray and Naseem, 2007

Following many field trials, GM crops are granted regulatory approval for commercial use as food, feed or for environmental release. As of October 2014, a total of 38 countries have granted regulatory approvals. From these countries, 3,083 regulatory approvals have been issued for 27 GM crops and 357 GM events. 1,458 are for food use (direct or processing), 958 for feed use (direct or processing) and 667 for environmental release or planting. Japan has the most number of approvals (201), followed by the US (171), and Canada (155) (see Figure 3.2).

Figure 3.2: Number of GM Crop Regulatory Approvals for Commercial Use by Country from 1994 to 2014



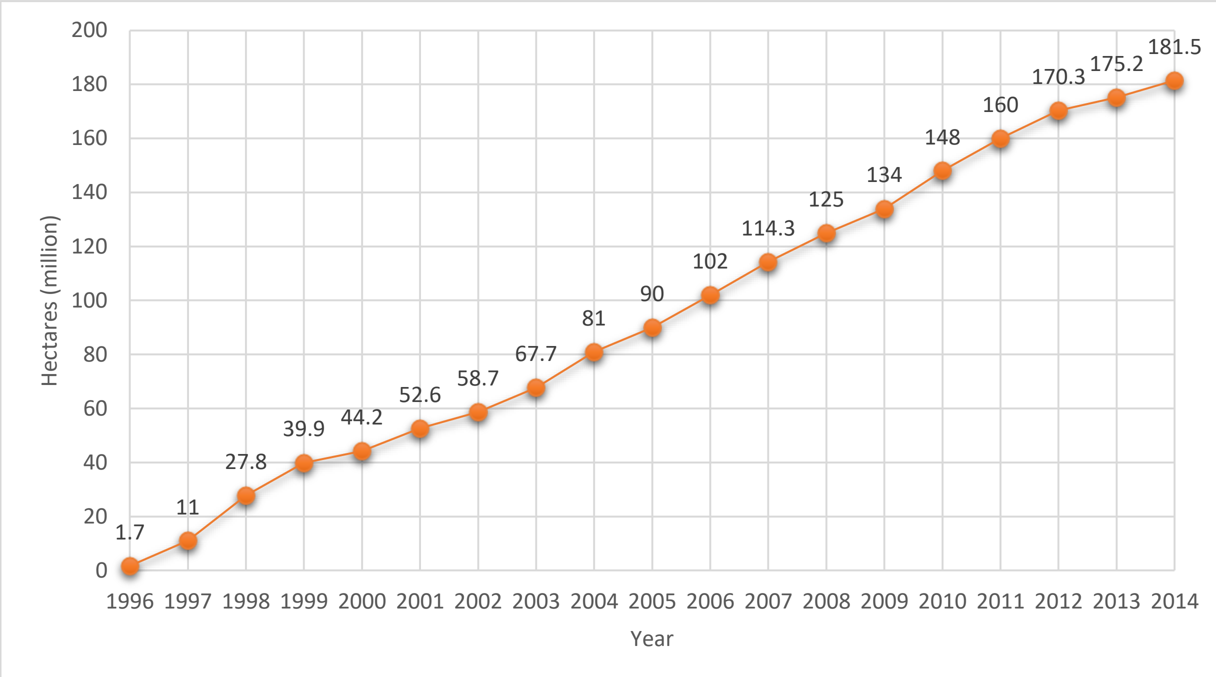
Source: ISB, 2015

Regulatory approvals for commercial use have been attributed to several interrelated factors including: government policies and institutional frameworks that support the development of agricultural biotechnology, a scientific structure and on-going investment in agricultural biotechnology R&D, the regulation of GM seed markets and the enforcement of IP rights, and increasingly competitive global markets amidst stagnating agricultural sectors and output (Fukuda-Parr, 2007).

3.3.2 GM Crops by Country and Crop

The global adoption of GM crops has increased at an annual rate of between 3% and 4% from 1.66 million hectares in 1996 to 181.5 million hectares (approximately 10% of global cropland) in 2014 making GM crops the fastest adopted crop technology in the modern era (see Figure 3.3).

Figure 3.3: Global Area of GM Crops in Millions of Hectares from 1996 to 2014



Sources: James, 2011, 2013, 2014, 2015

In 2014, there were 28 countries (where more than 60% of the world's population reside) that adopted GM crops. Among developed countries, the US is the leading grower with 73.1 million hectares in maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, and wheat, followed by Canada with 11.6 million hectares in canola, maize, soybean, and sugar beet. Among developing countries, Brazil followed by Argentina are the leading growers with 42.2 million hectares and 24.3 million hectares respectively in soybean, maize, and cotton. India grows 11.6 million hectares in cotton and China grows 3.9 million hectares in cotton, papaya, poplar, tomato, and sweet pepper (see Table 3.5).

Table 3.5: Global Area of GM Crops in Millions of Hectares by Country in 2014

Rank	Country	Area (million hectares)	GM Crops
1	US	73.1	Maize, soybean, cotton, canola, sugar beet, alfalfa, papaya, squash
2	Brazil	42.2	Soybean, maize, cotton
3	Argentina	24.3	Soybean, maize, cotton
4	India	11.6	Cotton
5	Canada	11.6	Canola, maize, soybean, sugar beet
6	China	3.9	Cotton, papaya, poplar, tomato, sweet pepper
7	Paraguay	3.9	Soybean, maize, cotton
8	Pakistan	2.9	Cotton
9	South Africa	2.7	Maize, soybean, cotton
10	Uruguay	1.6	Soybean, maize
11	Bolivia	1.0	Soybean
12	Philippines	0.8	Maize
13	Australia	0.5	Cotton, canola
14	Burkina Faso	0.5	Cotton
15	Myanmar	0.3	Cotton
16	Mexico	0.2	Cotton, soybean
17	Spain	0.1	Maize
18	Colombia	0.1	Cotton, maize
19	Sudan	0.1	Cotton
20	Honduras	<0.05	Maize
21	Chile	<0.05	Maize, soybean, canola
22	Portugal	<0.05	Maize
23	Cuba	<0.05	Maize
24	Czech Republic	<0.05	Maize3
25	Romania	<0.05	Maize
26	Slovakia	<0.05	Maize
27	Costa Rica	<0.05	Cotton, soybean
28	Bangladesh	<0.05	Brinjal (eggplant)

Source: James, 2015

A location quotient is ($LQ = \frac{\frac{X}{Y}}{\frac{X'}{Y'}}$) a useful way of quantifying GM cropland area relative to total cropland area. Assuming *X* is the amount of GM cropland area in a particular country, and *Y* is the total amount of cropland area in the same country, X/Y is then the over- or under-representation of GM cropland in a given country relative to global patterns. Also, assuming *X'* is the amount of GM cropland area globally and *Y'* is the amount of cropland area globally, then the LQ or the relative concentration of GM cropland in one country to the globe is (*X/Y*)/(*X'/Y'*). When the location quotient equals 1, this indicates that GM cropland area is equally concentrated relative to total cropland area in the country and the globe, while a location quotient of less than 1 indicates that GM cropland area is less concentrated relative to total cropland area in the country and the globe, and a location quotient of more than 1 indicates that GM cropland area is more concentrated relative to total cropland area in the country and the globe. For example, a location quotient for GM crops of 1.50, 1.48, and 1.47 for Paraguay, the US, and Canada respectively indicates that in these countries GM cropland area is more concentrated relative to total cropland area in the country and the globe whereas a location quotient for GM crops of 0.01, 0.02, and 0.03 for Australia, Mexico, and Spain respectively indicates that in these countries GM cropland area is less concentrated relative to total cropland area in the country and the globe. Also, while in absolute terms GM cropland area for both Canada and India is 11.6 million hectares, the location quotient is 1.47 for Canada and 0.53 for India which indicates a much greater concentration of GM cropland relative to total cropland area in Canada than India (see Table 3.6).

Table 3.6: Location Quotient for GM Crops

Country	GM crop area in millions of hectares (X)	Crop area in millions of hectares (Y)	Global GM crop area in millions of hectares (X')	Global crop area in millions of hectares (Y')	LQ
US	73.1	408.7	181.5	1500	1.47818
Brazil	42.2	275.6	181.5	1500	1.265458
Argentina	24.3	149.3	181.5	1500	1.34512
India	11.6	179.6	181.5	1500	0.533785
Canada	11.6	65.3	181.5	1500	1.468113
China	3.9	514.6	181.5	1500	0.062634
Paraguay	3.9	21.5	181.5	1500	1.499135
Pakistan	2.9	36.1	181.5	1500	0.663904
South Africa	2.7	96.8	181.5	1500	0.230517
Uruguay	1.6	14.2	181.5	1500	0.931207
Bolivia	1	37.6	181.5	1500	0.2198
Philippines	0.8	12.4	181.5	1500	0.533191
Australia	0.5	405.5	181.5	1500	0.01019
Burkina Faso	0.5	12.1	181.5	1500	0.341507
Myanmar	0.3	12.5	181.5	1500	0.198347
Mexico	0.2	106.7	181.5	1500	0.015491
Spain	0.1	26.9	181.5	1500	0.030723

Sources: James, 2015; Helgilibrary, 2016

3.3.3 Economic Impacts of Adopting GM Crops

Many farm-level empirical studies about the economic impacts of adopting GM crops exist (see, for example, Barrows et al., 2013; Brookes and Barfoot, 2013; Gouse et al., 2004; 2006; IFPRI, 2009; Kathage and Qaim, 2012; Pray et al., 2002; Qaim, 2009; Qaim and de Janvry 2003; Yorobe and Quicoy, 2006). The primary impact of GM HT (largely tolerant to the broad spectrum herbicide glyphosate) technology has been to provide more cost effective and easier weed control for farmers. Also, some users of this technology have also derived higher yields from better weed control (relative to weed control obtained from conventional technology). The main source of additional production from this technology has been through the facilitation of no tillage production systems, therefore shortening the production cycle. The primary impact of GM IR (engineered to resist insects) technology has been the lowering of the levels of pest damage and hence delivering higher yields. Also, additional cost savings are derived from a significant decrease in the use of pesticides. One of the earliest analysis from the IFPRI (2009) provided a summary of 67 studies that showed predominantly positive economic impacts for farmers that adopted GM cotton in China (studies on other GM crops and countries were included, but GM cotton in China dominated the literature); however, the magnitude of the economic advantages varied widely according to the cropping season, geographical location, length of the period over which adoption and impacts were observed, and the particular point along the adoption path that was analyzed. Also, Qaim's (2009) summary of several studies that investigated yield and gross margin impacts when switching from conventional crops to GM cotton and GM maize found that GM cotton increased yields by 37%, 33%, 24%, and 22%, and gross margins by US$135, US$23, US$470, and US$91, in India, Argentina, China, and South Africa respectively, and GM maize increased yields by 34%, 11%, and 9%, and gross margins by US$53, US$42, and US$20, in the Philippines, South Africa, and Argentina respectively. In a more recent study, Barrows et al. (2013) examined yield gains on the intensive margin (plots switching from conventional to GM crops) and the extensive margin (new plots entering production). In 2010, the authors found that GM crops increased the supply of maize between 10% and 16%, cotton between 15% and 20%, and soybean between 2% and 39%. Yield increases can be translated into price effects given a range of estimated elasticity of supply and demand (see de Gorter &

Zilberman 1990). Accordingly, these supply impacts translate into 13% to 27% lower maize prices, 19% to 33% lower cotton prices, and 2% to 65% lower soybean prices.

More recent analysis by Brookes and Barfoot (2013) found an increase of US$19.8 billion in 2011 and US$98.2 billion from 1996 to 2011 in farm incomes globally from adopting GM maize, cotton, canola, and soybean. The largest gains in farm incomes in 2011 were in the maize sector, largely from yield gains. Cumulatively since 1996, GM maize has added nearly US$30 billion to the income of farmers globally. Substantial gains have also arisen in the cotton sector through a combination of higher yields and lower costs. Cotton farm income levels in GM adopting countries increased by US$6.73 in 2011 and US$32.5 billion from 1996 to 2011. Significant increases to farm incomes have also resulted in the soybean and canola sectors. GM soybeans increased farm incomes by US$3.89 billion in 2011, and $32.2 billion from 1996 to 2011. In the canola sector (largely North American) an additional US$3.1 billion has been generated from 1996 to 2011 (see Table 3.7).

Table 3.7: Global Farm Income Increases in Million US$ from Adopting GM Crops from 1996 to 2011

GM Crop	Farm income increase in 2011	Farm income increase from 1996 to 2011	Farm income increase in 2011 as percentage of total value of production of these crops in GM adopting countries	Farm income increase in 2011 as percentage of total value of global production of crop
Soybean	3,879.2	32,211.9	3.8	3.2
Corn	8,645.1	29,974.2	8.3	4
Cotton	6,726.5	32,48.73	15.1	11.9
Canola	433.2	3,131.4	1.4	1.2
Other	83.3	412.0	N/a	N/a
Total	**19,767.3**	**98,216.8**	**6.3**	**5.9**

Source: Brookes and Barfoot, 2013

Farm income benefits may be summarized in key GM crop adopting countries (see Table 3.8).

Table 3.8: Global Farm Income Increases in Million US$ from Adopting GM Crops by Country and Crop from 1996 to 2011

Country	Corn	Soybean	Cotton	Canola	Total
Argentina	891.20	12624.6	451.30	N/a	**13,967.10**
Australia	N/a	N/a	583.80	27.5	**611.30**
Bolivia	N/a	327	N/a	N/a	**327.00**
Brazil	2,228.40	4314.5	102.50	N/a	**6,645.40**
Burma	N/a	N/a	338.70	N/a	**338.70**
Canada	887.20	231.6	N/a	2862.5	**3,981.30**
China	N/a	N/a	13,067.80	N/a	**13,067.80**
Colombia	30.10	N/a	28.60	N/a	**58.70**
India	N/a	N/a	12,579.50	N/a	**12,579.50**
Mexico	N/a	4.9	175.30	N/a	**180.20**
Pakistan	N/a	N/a	334.20	N/a	**334.20**
Paraguay	N/a	732.4	N/a	N/a	**732.40**
Philippines	264.40	N/a	N/a	N/a	**264.40**
Romania	N/a	44.6	N/a	N/a	**44.60**
South Africa	891.10	7	34.60	N/a	**932.70**
Spain	139.10	N/a	N/a	N/a	**139.10**
Uruguay	11.70	83.4	N/a	N/a	**95.10**
US	24,607.80	13835.9	4,694.20	241.5	**43,379.40**
Other EU Countries	16.20	N/a	N/a	N/a	**16.20**

Source: Brookes and Barfoot, 2013

In terms of the cost farmers pay for accessing GM technology across the four main GM crops, the total cost in 2011 was equal to 21% of the total technology gains, inclusive of farm income gains plus cost of the technology payable to the GM seed supply chain (see Table 3.9).

Table 3.9: Global Cost of Accessing GM Technology in Million US$ Relative to the Total Farm Income in 2011

GM crop	Cost of technology	Farm income gain	Total benefit of technology to farmers and GM seed supply chain
Soybean	1,647.60	3,879.20	5,526.80
Corn	2476.2	1707.1	4183.3
Cotton	1071.6	7538.1	8609.7
Canola	140.20	6,559.60	6,699.80
Other	71.10	83.30	154.40
Total	**5,406.70**	**19,767.30**	**25,174.00**

Source: Brookes and Barfoot, 2013

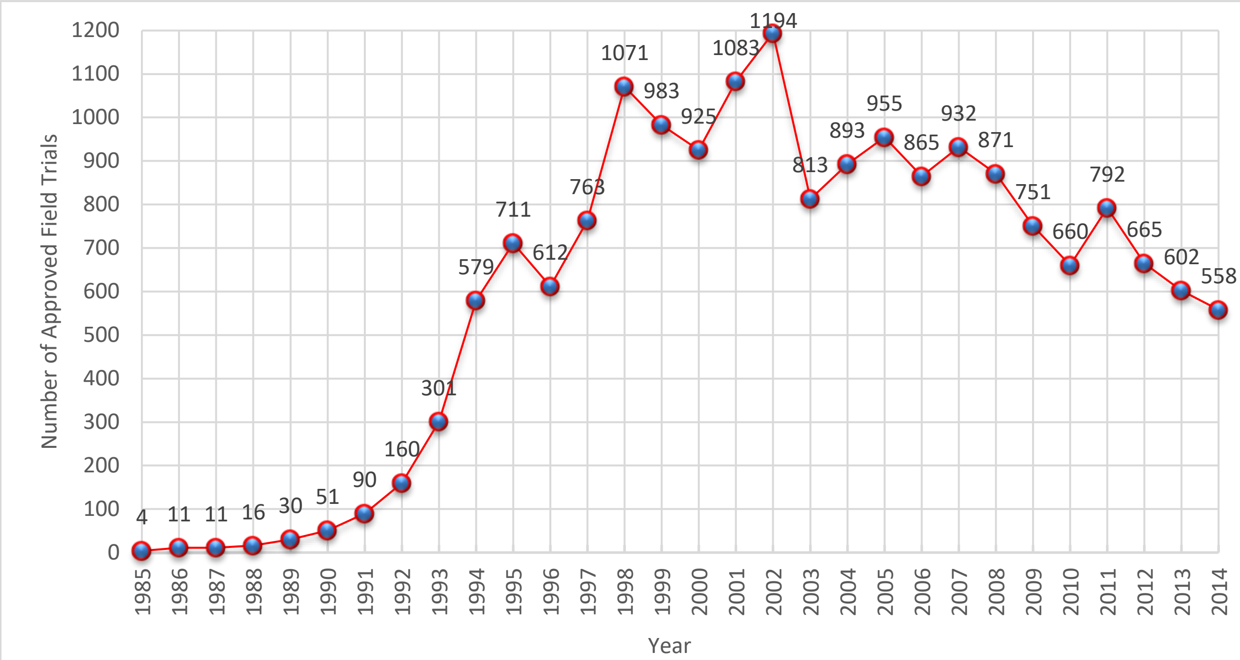
3.3.4 US Leads and Canada Follows

US government policies have strongly favoured the use of GM crops. Significant levels of public funding for biotechnology research that maintain the required administrative infrastructure have been committed. The federal government, through the Agricultural Research Service (ARS) of the US Department of Agriculture (USDA) spends well over US$125 million per annum on plant biotechnology. The US GM seed market is supported by large crop improvement efforts shared by four institutions: government (ARS/USDA), state agricultural experiment stations (SAESs), private companies, and universities (private and public). Before commercialization, all agricultural biotechnology products (mostly GM crops) must conform to standards set by state and federal statutes (Fernandez-Cornejo and Caswell, 2006; USDA and APHIS, 2013).

Under the Coordinated Framework for the Regulation of Biotechnology, federal oversight is shared by the USDA, the US Environmental Protection Agency, and the US Food and Drug Administration. The USDA's Animal and Plant Health Inspection Service (APHIS) plays a central role in regulating field trials of GM crops. GM cops that meet six specific criteria undergo an administratively streamlined process known as a notification. Under a notification, applicants provide information on the nature of the plant and introduced genes, descriptions of genetic modifications, size of the introduction, and origin and destinations for movement or the location of a field trial. For GM crops that do not meet the criteria for a notification, a permit is required. This process involves a more comprehensive review. In addition to the data required for a notification, permit applicants must describe how they will perform the field trial, including specific measures to reduce the risk of harm to other plants, so the tested organisms remain confined and do not persist after completion of the field trial. Following either a notification or permit, APHIS issues authorizations for field releases of those GM crops that are categorized as 'regulated articles' allowing an applicant to pursue field trials. Following field trials, an applicant may petition APHIS for a 'determination of nonregulated status' to allow commercialization of the product. Once APHIS issues a determination of nonregulated status the GM crop is no longer considered a regulated article and can be moved and planted without APHIS oversight (USDA and APHIS, 2012).

The number of field release notifications and permits issued by APHIS increased from 4 in 1985 to a peak of 1,194 in 2002 and then decreased to 558 in 2014 (see Figure 3.4).

Figure 3.4: Number of Approved Field Trials in the US from 1985 to 2014



Source: ISB, 2015

A notification and permit may include many release sites and authorize many different gene constructs (ways that the gene of interest is packaged with other elements) to be tested at each site. Therefore, while the number of APHIS notifications and permits peaked in 2002, a more comprehensive measure of the amount of R&D activity in agricultural biotechnology includes the number of authorized sites and authorized constructs, which have increased very rapidly since 2006 (see Table 3.10).

Table 3.10: Number of Notifications and Permits, Authorized Sites, and Authorized Constructs Approved by APHIS from 1989 to 2012

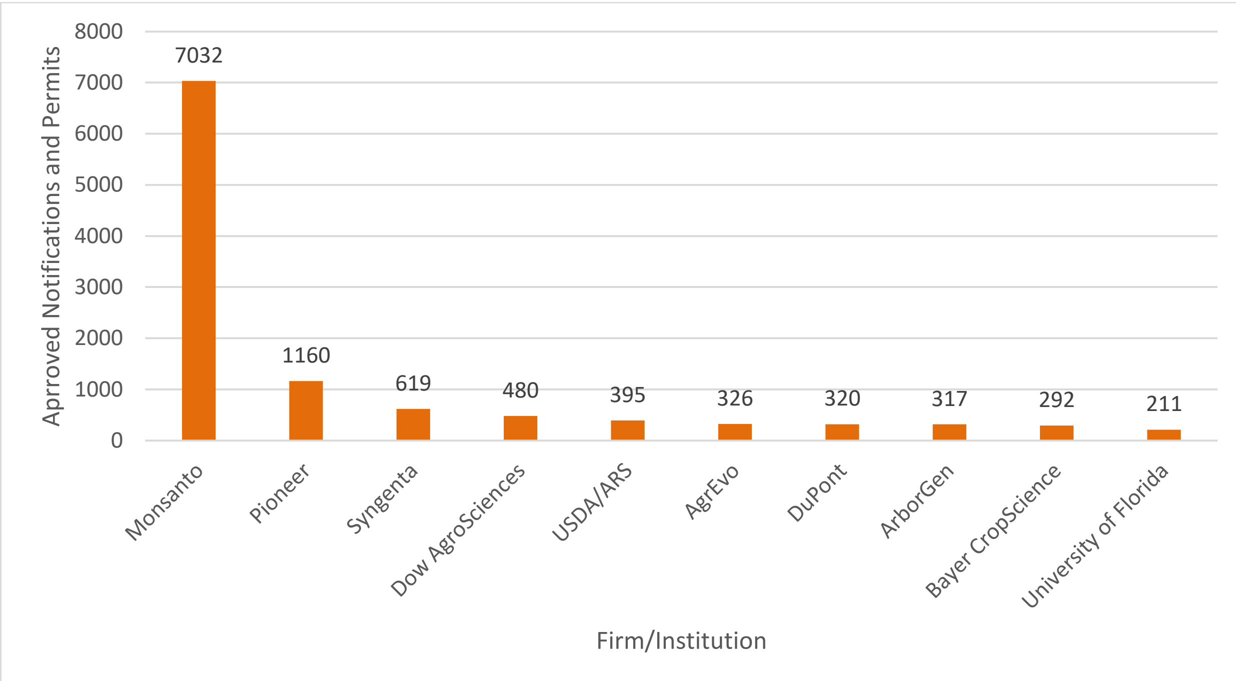
Year	Notifications and Permits	Authorized Sites	Authorized Constructs
1989	30	12	74
1990	51	14	142
1991	90	10	226
1992	160	121	427
1993	301	455	870

1994	579	1669	1926
1995	711	3690	2666
1996	612	2745	2305
1997	763	3427	2650
1998	1071	4781	2830
1999	983	4134	3502
2000	925	3836	3126
2001	1083	5831	3208
2002	1194	5111	3234
2003	813	2910	2650
2004	893	4523	2851
2005	955	4939	3042
2006	865	4327	18532
2007	932	3623	63217
2008	871	7744	125365
2009	751	6751	217502
2010	660	6626	297422
2011	792	10128	395501
2012	665	9133	469202

Source: Fernandez-Cornejo et al., 2014

In 2014, the top holder of notifications and permits among the top ten firms and institutions in the US was Monsanto with 7,032 or 63% followed by Pioneer with 1160 or 10%. Private sector firms held 10,546 or 94.5%, the USDA/ARS held 395 or 3.6%, and the University of Florida held 211 or 2% (see Figure 3.5).

Figure 3.5: Number of Issued Notifications and Permits Held by Firms and Institutions in the US in 2014



Source: ISB, 2015

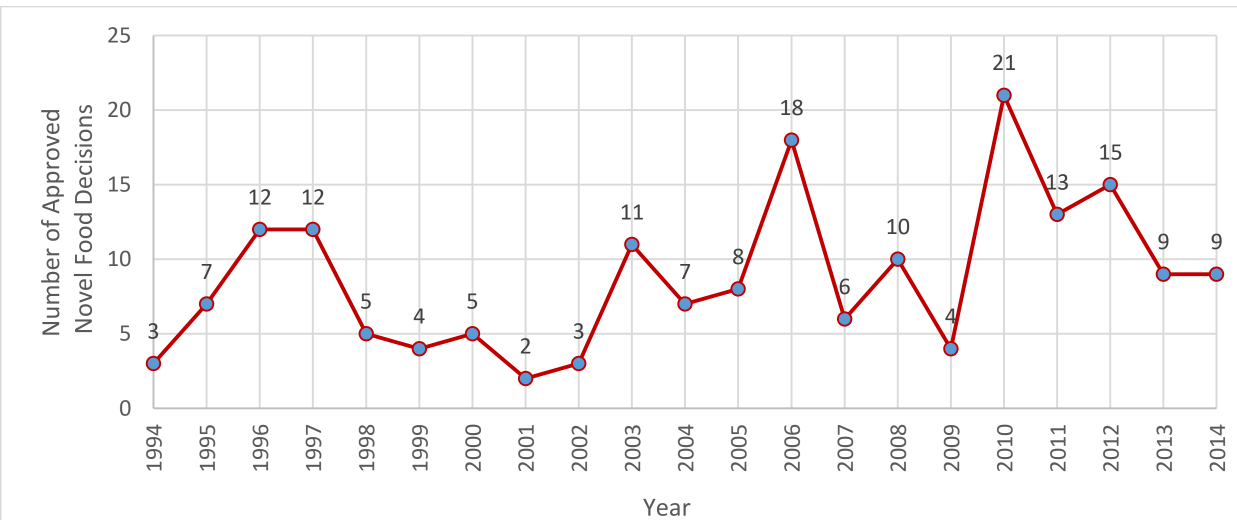
The US regulatory model for biotechnology has been employed in Canada, as well as other countries such as Mexico and Australia. The focus of the Canadian model has been on competitiveness and regulatory intervention. The model employs product-based regulations within existing vertical regulatory jurisdictions, where supplemental regulations or guidelines have been developed to deal with new concerns and risks associated with novel organisms and products. Furthermore, regulatory decision-making employs the reasonably certain interpretation of the precautionary principal and there are a limited number of actors that directly influence regulatory decision-making (Isaac et al., 2001).

In 1993, the Canadian Federal Regulatory Framework for the regulation of biotechnology products was announced by the Canadian government. The framework is intended to ensure that the benefits of biotechnology products and processes are realized in a way that protects health, safety, and the environment. One of the key principles adopted by the regulatory departments includes the use of existing laws and regulatory departments. Regulatory authority for food products derived from biotechnology falls under several federal departments and agencies. Health Canada is responsible for assessing the human health safety of products derived through biotechnology including foods, drugs, cosmetics, medical devices, and pest control products. The CFIA shares responsibility for the regulation of products derived from biotechnology including plants, animal feeds, fertilizers, and veterinary biologics. For GM crops, the CFIA assesses the potential risk of adverse environmental effects, authorizes and oversees import permits, confined trials, unconfined release, and variety registration. In 1994, the Guidelines for the Safety Assessment of Novel Foods were published by Health Canada. The guidelines are based on internationally accepted principles for establishing the safety of foods derived from GMOs, and were developed in consultation with other government agencies, consumers, and industry. In 2006, Health Canada revised the guidelines to reflect the advancement of methods and knowledge regarding product review (Health Canada, 2012).

In Canada, novel foods are defined in The Novel Foods Regulation as products that have never been used as a food; foods which result from a process that has not previously been used for food; or, foods that have been modified by genetic manipulation. This last category of foods have been described as GM foods, genetically engineered foods or biotechnology-derived foods. Health Canada is responsible for ensuring that all foods, including those derived from biotechnology, are safe prior to their entering into the Canadian food system. The Novel Foods Regulation requires that notification be made to the Health Products and Food Branch by the company who wants to sell the product prior to the marketing or advertising of a novel food. Pre-market notification permits Health Canada to conduct a thorough safety assessment of all biotechnology-derived foods to demonstrate that a novel food is safe and nutritious before it is allowed in the Canadian marketplace (Health Canada, 2012).

From 1994 to 2014, Health Canada approved 184 novel foods (see Table 3.11).

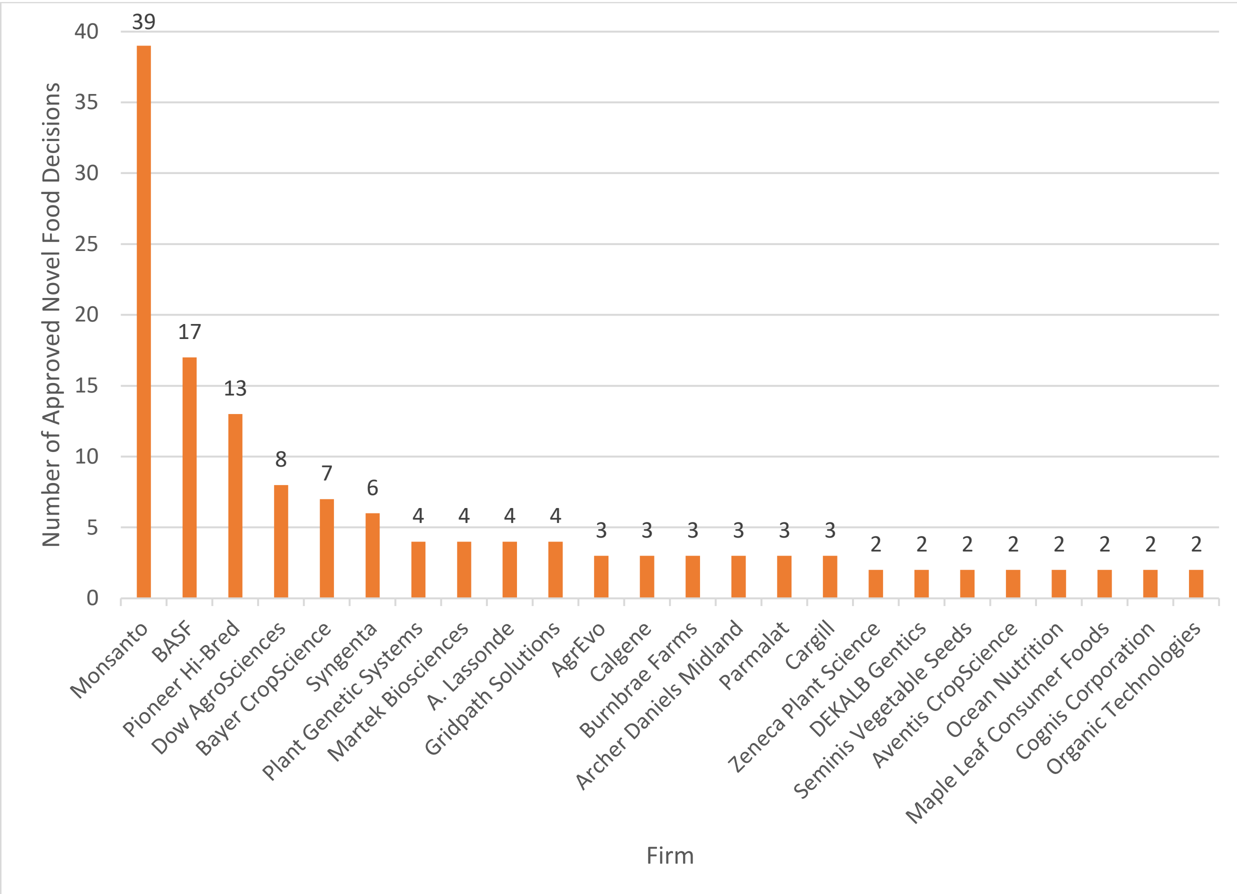
Table 3.11: Number of Approved Novel Food Decisions by Health Canada from 1994 to 2014



Source: Health Canada, 2015

In 2014, the top holder of approved novel food decisions among the top 24 firms in Canada was Monsanto with 39, followed by BASF with 17, and Pioneer with 13. Private sector firms held 181 or 98% of approved novel food decisions, Agriculture and Agri-Food Canada held 1, the University of Saskatchewan held 1, and the University of British Columbia held 1 (see Figure 3.6).

Figure 3.6: Number of Approved Novel Food Decisions by Health Canada by Firm from 1994 to 2014



Source: Health Canada, 2015

Four GM crops are grown in Canada: canola, corn, soybean, and sugar beet (see Table 3.12).

Table 3.12: Canadian Area of Conventional and GM crops in Thousands of Hectares by Crop from 2007 to 2012

Crop Area (hectares in thousands)	2007	2008	2009	2010	2011	2012
Corn for grain	1,391.50	1,204.00	1,203.50	1,214.30	1,217.70	1,472.40
Fodder corn	246.4	244.9	312.2	244.6	205.9	230.7
Total corn	1,637.90	1,448.90	1,515.70	1,458.90	1,423.60	1,703.10
GM corn	636.7	632.6	743	795.1	811.3	1,201.40
GM corn as percent of total	39%	44%	49%	54%	57%	71%
Soybean	1,180.10	1,211.30	1,395.30	1,483.00	1,549.90	1,746.50
GM soybean	529.7	604.7	604.6	658.1	742.3	1,130.10
GM soybean as percent of total	45%	50%	43%	44%	48%	65%
Canola	5,959.50	6,398.90	6,555.80	6,806.10	7,633.20	8,608.70
GM canola	4,767.60	5,119.10	5,244.60	5,444.90	6,106.60	8,178.30
GM canola as percent of total	80%	80%	80%	80%	80%	95%

Source: Evans and Lupescu, 2012

GM sugar beet has been planted in Canada since 2008. Production is concentrated in Taber, Alberta where Canada’s only sugar beet processing plant is located. In 2010, 96% of the sugar beet crop (approximately 13,000 ha) was GM sugar beet (Evans and Lupescu, 2012). Currently, I am not aware of any published analysis of the economic impact of GM sugar beet in Canada.

Most of Canada’s canola production is centered in the western provinces of Alberta, Saskatchewan, and Manitoba. Approximately 15% of the Canadian canola crop is consumed in Canada in various forms. The remainder 85% of GM canola seed, oil, and meal are exported to destinations such as the US, Japan, Mexico, and China (Evans and Lupescu, 2012). The commercialization of herb-tolerant canola began in 1996 and by 2014 farmers planted 8 million hectares accounting for 95% of all the canola grown in Canada and 69% of all GM crops.

The overall impact on profitability from adopting GM canola (inclusive of yield improvements and higher quality) has been an increase of between CDN$22/ha and CDN$74/ha. The annual total national farm income benefit from using the technology has risen from $6 million in 1996 to $404 million in 2011. The cumulative farm income benefit over the 1996-2011 period was $2.86 billion (see Table 3.13).

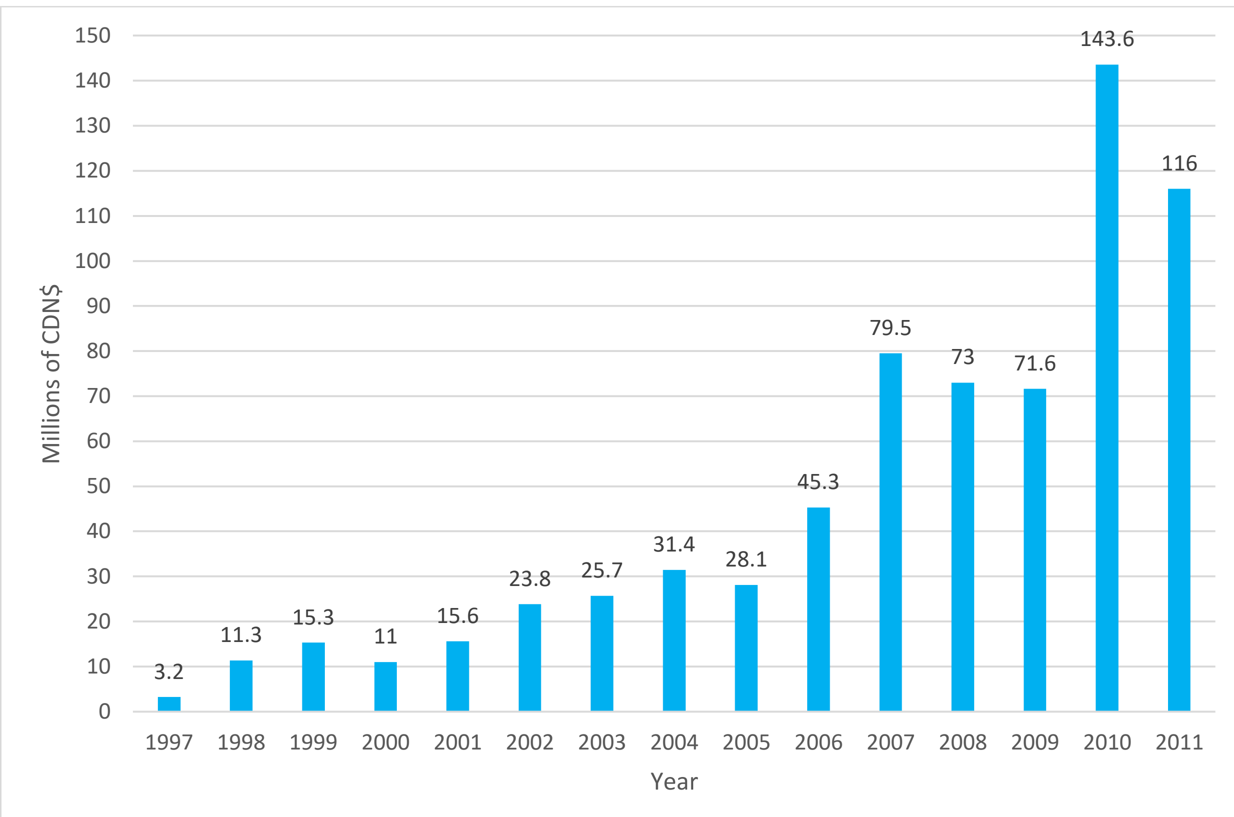
Table 3.13: Farm Level Income Impact from Adopting GM Canola in Canada from 1996 to 2011

Year	Cost savings in CDN$/ha	Cost saving inclusive of cost of technology in CDN$/ha	Net cost saving/increase in gross margins in CDN$/ha	Increase in farm income at a national level in million CDN$	Increase in national farm income as percent of farm level value of national production
1996	28.59	-4.13	45.11	6.23	0.4
1997	28.08	-4.05	37.11	21.69	1.17
1998	26.21	-3.78	36.93	70.18	3.43
1999	26.32	-3.79	30.63	90.33	5.09
2000	26.32	-3.79	22.42	59.91	5.08
2001	25.15	-1.62	23.1	53.34	5.69
2002	24.84	-3.59	29.63	61.86	6.17
2003	28.04	-4.05	41.42	132.08	6.69
2004	21.42	4.44	19.09	70.72	4.48
2005	23.11	4.5	32.9	148.12	6.56
2006	34.02	16.93	50.71	233.13	8.09
2007	35.44	17.46	66.39	341.44	7.54
2008	35.53	17.39	64.76	361.7	6.36
2009	37.76	17.99	63.62	369.7	7.32
2010	35.15	16.36	73.99	448.27	6.11
2011	43.32	25.35	56.79	404.33	4.99

Source: Brookes and Barfoot, 2013

GM corn has also been grown commercially in Canada since 1996. In 2011 it accounted for 70% of the 1.2 million ha of corn grown in Canada. Traditionally, Quebec and Ontario are the primary corn-growing regions, accounting for 86 percent of total Canadian corn. In Quebec, 74% of the total corn crop was GM corn in 2012, up from 47 percent in 2007, while in Ontario 75% of the total corn crop was GM corn in 2012, up from 41 percent in 2007. More recently there has also been an upward trend in the planting of GM corn in Manitoba (Evans and Lupescu, 2012). The additional farm revenue from the use of GM corn at the national level was CDN$116 million in 2011 and cumulatively CDN$694.4 million since 1996 (see Figure 3.7).

Figure 3.7: National Farm Revenue from Adopting GM Corn in Canada from 1996 to 2011 in Millions of CDN$



Source: Brookes and Barfoot, 2013

GM soybean was first planted in Canada in 1997. Traditionally, Quebec and Ontario have been the primary soybean growing regions in Canada, accounting for 92% of total soybean acreage in 2007. With the rise of Manitoba as a soybean producing province, the combined share for Quebec and Ontario has slowly declined over time. In 2012, Ontario and Quebec accounted for approximately 78% of total soybean acreage, while Manitoba's share increased from 8% in 2007 to 20% in 2012 (Evans and Lupescu, 2012). The average farm income benefit has been between CDN$14/ha and CDN$40/ha and the increase in farm income at the national level was CDN$12.3 million in 2011. The cumulative increase in farm income since 1997 has been CDN$155.5 million (see Table 3.14).

Table 3.14: Farm Level Income Impact from Adopting GM Soybean in Canada from 1997 to 2011

Year	Cost savings CDN$/ha	Net cost saving/increase in gross margins in CDN$/ha	Impact on farm income at a national level in million CDN$	Increase in national farm income as percent of farm level value of national production
1997	64.28	41.17	0.041	0.01
1998	56.62	35.05	1.72	0.3
1999	53.17	31.64	6.35	1.29
2000	53.2	31.65	6.71	1.4
2001	49.83	29.17	9.35	3.4
2002	47.78	27.39	11.92	2.79
2003	49.46	14.64	7.65	1.47
2004	51.61	17.48	11.58	1.48
2005	55.65	18.85	13.3	2.26
2006	59.48	23.53	17.99	2.22
2007	61.99	24.52	16.87	1.57
2008	56.59	18.28	16.08	1.45
2009	55.01	12.02	10.46	0.87
2010	43.93	17.75	13.11	0.68
2011	44.65	18.55	12.35	0.65

Source: Brookes and Barfoot, 2013

The agriculture and agro-food sector in Canada uses biotechnology in a variety of ways to produce agricultural inputs and food products including: veterinary drugs and biologics (drugs used for the treatment or diagnosis of infectious diseases of animals); plants with novel traits (crops and horticultural plants); bio-pesticides (for insect, disease, and pest control); novel fertilizer supplements or bio-fertilizers (to improve plant growth); livestock feed and feed additives; and novel foods. Products are regulated by government agencies in order to protect human, animal, and environmental health, and to protect consumers against fraud. Regulation also serves to maintain international quality and safety standards that facilitate trade (CFIA, 2007).

3.4 Conclusion

Over the past century, plant breeding has developed incrementally by harnessing advances in plant biology, supplemented at times by traditional empirical knowledge (lore), and informed by the principles of Mendelian genetics. Public sector institutions emerged to catalyze formal crop improvement, focusing on yield with high input requirements and wide adaptability. The education, research, and institutional system triad commonly found in developed countries was exported to developing countries to foster agricultural development and food security mainly through the development of broadly adapted germplasm.

Since the 1970s, the common heritage principle has been turned on its head with the gradual encroachment of claims for control over access to and use of genetic resources through the introduction of IP laws. In the 1980s, patents entered plant breeding initially through court decisions in the US via association with biotechnology. The series of biotechnology patenting cases that followed during the 1980s and 1990s not only greatly expanded the legal boundaries of patentable living matter, but also narrowed the traditional seed saving exemptions for farmers.

In addition to the introduction of patents into agriculture has been significant public and private investments in agricultural R&D. Governments have entered this arena to accommodate the needs of capital by providing significant outlays of investment necessary for the development of the R&D infrastructure. This not only mitigates the associated risks of venturing into such avenues, but gives extra incentives to develop agricultural science and technology with research institutions that effectively have taken up the task set for them by governments and corporate actors.

With the agricultural R&D infrastructure firmly set in place, there has been greater concentration and centralization among GM seed and agrochemical corporations since the 1980s. Corporations which had no expertise in either biotechnology or plant breeding began to massively invest in developing GM varieties. As a result, several of these companies grew exponentially from relatively small-scale enterprises to large-scale corporations. Concentration among large-scale corporations has resulted in centralisation through mergers and acquisitions of small-scale enterprises by large-scale ones. The result has been greater control of R&D and market imperatives in the agricultural biotechnology industry by a handful of multinational corporations.

The fulfillment of R&D efforts has been the rapid (albeit temporally and geographically uneven) global adoption and production of GM crops. This has confirmed some of the claims about the economic benefits of adopting and producing GM crops; however, the magnitude of the economic advantages vary widely according to the cropping season, geographical location, length of the period over which adoption and impacts were observed, and the particular point along the adoption path that was analyzed (IFPRI, 2009). Also, the majority of the GM crops that have been developed and released for commercial use have been genetically engineered for the production requirements and benefit of farming in developed countries. This has led to a narrow focus on a few commercially important crops and engineered traits, while minor crops and traits remain largely ignored (Fukuda-Parr, 2007). For example, the US continues to be the leading grower of GM crops, accounting for 40% of global hectares of mostly maize, soybean, and cotton while all developing countries combined account for only 53% of global hectares of mostly the same crops (James, 2015). Also, some authors have questioned whether or not the structure of scientific research mitigate against developing products that are beneficial for small-scale resource-poor farmers. The incentives and institutional relations of GM crop research requires a vastly more advanced infrastructure, expertise, and expense than did earlier methods of seed improvement. Most of the research and innovation needed to create functional GM crops has been done in the academic institutions of developed countries (Altieri and Rosset, 1999). The changing role of the university toward an institution more aligned with private sector interests and orientations has involved the expansion of the state-university-industry nexus and a dramatic shift in the way university research is expected to contribute to public good. This has been facilitated by the selling of publicly funded research into private hands in what has been referred to as 'academic capitalism' (Glenna et al., 2007).

Moving away from analyses that regard technology as an exogenous and socially neutral force in the development of capitalism, I provide a different perspective by situating agricultural biotechnology in the context of capitalism as a form of society. Accordingly, the development, adoption, and production of GM crops is primarily motivated by capitalism's on-going need to enhance the possibility of value accumulation through innovation, not only in the agricultural and agro-food sectors, but also in the economy as a whole. The aggravating conditions of capitalist valorization and accumulation in the agricultural sector, as in other sectors of the economy, have given rise to what is often referred to as the 'biotechnology revolution'. The specific developments in agricultural biotechnology create the possibility for entirely new conditions for the accumulation of capital, and give rise to new economic contradictions and significant social disruptions.

Chapter Four

The State, Civil Society, and the Canadian Agricultural Biotechnology Industry

4.1 Introduction

An important idea in Marxism is that a given object or process is connected to many other objects or processes and it is subjected to contradictory movements. This is the case for biotechnology. There are complex ways in which biotechnology, agricultural production, and the interventions by the state and civil society organizations are interconnected. Advanced capitalism is characterized by a general (albeit temporally and spatially uneven) tendency towards technological change in its various forms. In the contemporary era, biotechnology is one such form. As with all forms of technology, its emergence is a contradictory process. As an industrial phenomenon, biotechnology may be considered as an opportunity for individual segments of the capitalist class for accumulation of exchange value as well as a capitalist growth strategy at the sectoral level. Its emergence is indicative of an instantiated counter-struggle on the part of specific capitals against impinging price competition in the agricultural industry and, at a macro-scale, of the more general intensifying decline in the rate of profit in advanced industrial economies. The emergence and utilization of biotechnology both as a means of production and as a means of increasing (monopolistic) profit is part of a wider process of market-oriented reforms in the agrarian sector occurring at national and international scales. This process is not only economic but also political. The large-scale introduction of biotechnology would not have been possible without the interventions on the part of the state, which generally tends to play an enabling role by assisting capitalists in the development and adoption of novel biotechnology products. While capitalist strategies and state interventions are pushing for the introduction of biotechnology, there are forces (e.g., civil society organizations) whose aim is to at least partly resist the expansion of the market for biotechnology. This means that the outcomes of market-based restructuring in general and the use and consequences of biotechnology in particular are anything but automatic.

The purpose of this chapter is to investigate the role of the state and civil society organizations in relation to the development, adoption, and production of GM crops at local and national scales. I address the following questions: in what ways has the federal government of Canada supported R&D) and innovation? What are the objectives of the Canadian biotechnology strategy and policies? How have the federal government of Canada's biotechnology regulatory practices supported industry initiatives and addressed public concerns? What effect have the federal government of Canada's biotechnology policies and regulatory practices had on the adoption and production of GM crops? How does resistance by various civil society organizations affect the expansion of the market for biotechnology products? Why do various government agencies continue to promote the development, adoption, and production of GM crops despite on-going public resistance? I argue that the development, adoption, and production of GM crops in the Canadian context represents in part a significant attempt by the state to secure the ongoing capitalist development of the agricultural biotechnology industry. This occurs through a complex array of processes, on the one hand, by a variety of government agencies that are necessary for the procurement of costly generic scientific and technological R&D, legislation, and regulation, and on the other hand, by instances of the state neutralizing or countering the political struggles waged by various civil society organizations that have challenged such outcomes. This signifies an economic geography at the national and international scales in which 'competitiveness' is heralded resulting in the support of innovation systems and the expansion and protection of value accumulation, while simultaneously civil society action seeks to challenge pressures toward market-oriented restructuring and reform. The tension between compliant government structures and resistant civil society action counter the encroachment of the capitalist market.

To support the argument, I examine the *Biotechnology in Canada* report, the establishment of the Canadian Biotechnology Strategy and the National Biotechnology Advisory Committee, and the Canadian biotechnology regulatory practices. In addition, I incorporate select responses from 19 interviews conducted between January and August 2015 with personnel from government agencies such as AAFC and Health Canada and civil society organizations such as Greenpeace Canada and the CBAN. AAFC (2016) is responsible for governing agricultural production, farming income, R&D, inspection, the regulation of animals and plants, and rural development. Personnel that were interviewed were from the Research Branch. These respondents provided insights about different solutions and opportunities based on science that the AAFC has implemented to support competitiveness and the sustainability of the agriculture and agri-food sector. Health Canada (2011) is responsible for national public health. Personnel that were interviewed were from the science and research division. These respondents provided insights about the costs to Health Canada associated with conducting applied science activities, such as food inspection, disease tracking, and compliance testing of consumer products. Greenpeace Canada (2015b) is known for its work among civil society organizations in Canada. Personnel that were interviewed have been involved in the campaign for sustainable agriculture. This campaign rejects genetically engineered organisms (GMOs) and promotes biodiversity and socially responsible farming. The CBAN (2015a) promotes food sovereignty and democratic decision-making regarding science and technology issues in order to protect the integrity of the environment, health, food, and the livelihoods of people in Canada. This is accomplished by facilitating, informing, and organizing civil society action, researching, and providing information to government for policy development. Personnel that were interviewed have been involved in various anti-GMOs campaigns.

The chapter is organized in the following way. I bring into focus Canada's biotechnology R&D initiatives (section **4.2 Canadian Research and Development and Innovation**), strategy, policy (section ***4.2.1 Canadian Biotechnology Strategy and Policy***), and regulatory framework (section ***4.2.2 Canadian Agricultural Biotechnology Regulation***), and their economic impact on the biotechnology industry (section **4.3 Market Impact of the Canadian Agricultural Biotechnology Industry**). Moreover, I highlight some of the rising contestations from civil society organizations (section **4.4 Rising Contestations**). In the conclusion (section **4.5 Conclusion**) I provide a summary the findings, draw out some conceptual implications, and situate the contribution of the chapter in the broader academic literature.

4.2 Canadian Research and Development and Innovation

The Government of Canada has for many years evinced a sense for technological optimism in which the idea is propagated that the development of science and technology will reap great socio-economic benefits for the Canadian population (see, for example, Government of Canada, 2003; Health Canada, 2005; for a critical analysis see Smardon, 2014). In the 1960s, the federal government began to fund industrial R&D on a broad basis through direct grants and tax incentives. Under various governments, the federal state established several new programs: the Defence Industrial Research program; the Industrial Research Assistance Program, which was housed in the National Research Council (NRC); the Program for the Advancement of Industrial Technology; and the Industrial Research and Development Incentives Act program. Such efforts expanded throughout the 1970s as major new tax credits for industrial R&D were added as well as contracting out federal research needs to the private sector. These incentives quickly grew to become the core source of federal support for R&D in Canadian industry.

R&D and innovation continued to receive a great deal of attention in the 1980s and 1990s as more initiatives were implemented at the federal level. Although there were fewer grants and contributions to industry these were compensated for by rising levels of spending on R&D contracts with industry and a continued commitment to R&D tax credits. The Industrial Regional Development Program (created as part of the new department of Regional Industrial Expansion) led to expanded funding in the early to mid-1980s. The Scientific Research Tax Credit led in the same period to more federal money being focused on tax incentives. The InnovAction initiative in 1987 led to a new focus on ‘research networks’ and to the Networks of Centres of Excellence program (involving networks of research connections between industry and the universities) in the latter part of the 1980s; and a new federal department called Industry, Science, and Technology Canada was formed to manage the promotion of R&D and innovation in Canadian industry.

The focus on promoting domestic technological capacities continued into the early 1990s through the establishment of the Prosperity Initiative. Reflecting a movement away from grant-based forms of assistance in the post-free trade period, grants and contributions to industry from the NRC and from the newly formed Industry, Science and Technology Canada declined in the latter part of the 1980s and remained at a lower level in the early 1990s. This, however, was compensated for by rising levels of spending on R&D contracts with industry and a commitment of the federal state to R&D tax credits. Although the Scientific Research Tax Credit was eliminated in the face of widespread abuse, the broader Scientific Research and Experimental Development tax credit was created, which was among the most generous in the advanced capitalist world in the 1980s and the 1990s.

R&D grants and contributions to the business enterprise sector rebounded from their lower level from 1995 to 1997 to levels higher than in the period before the 1995 budget. A range of other new initiatives reflected the increased influence of “systems of innovation” thinking. These included the Partnerships in Knowledge program; the Synergy Awards program; the creation of Industrial Research Chairs; Strategic Projects for pre-competitive research involving universities and industry; and Research Partnership Agreements among universities, industry, and government organizations.

In addition to these initiatives were various sectoral strategies, such as the Canadian Biotechnology Strategy and new program and spending initiatives undertaken in the latter part of the 1990s, ranging from the creation of the Canadian Foundation for Innovation, which provided funding for new research infrastructure projects in university and non-profit institutions, to expanded funding for existing programs, such as the Networks of Centres of Excellence. Through these various programs and initiatives over a forty-year period, the federal state spent substantial sums of money in pursuit of the goal of expanded industrial R&D and greater domestic technological capabilities, particularly through the creation of R&D tax incentives that provided higher levels of funding than in other advanced capitalist countries (Smardon, 2014, 3-28).

4.2.1 Canadian Biotechnology Strategy and Policy

The Government of Canada's biotechnology strategy and policy were in part an attempt at stimulating the national economy and international competitiveness through innovative, research-intensive, high-technology industries during the general global economic slowdown following the so-called 'golden age of capitalism'. As Canada's economic situation steadily declined amid the economic recession and lagging manufacturing throughout the 1970s and 1980s, concern for the national economy and industrial performance emerged as major issues. In one of my interviews, an employee from the AAFC remarked about the important role of agricultural biotechnology as part of the solution for ameliorating the more general crisis in agriculture.

> Part of the entire strategy by the government had to do with the crisis that many nations, not only Canada, were facing in the 1980s and 1990s. I mean you could look it up yourself, farmers in Canada, and around the world as a matter of fact were not doing well, farming was in trouble,

> really. There was talk about putting money into biotech, not just in agriculture but other places as well, to generate the sector, although this was only part of the solution. There were consultations that were taking place with industry, farmers, and people from the public about the kind of solutions we were going to come up with to get us out of this mess. You know, biotech was going to be part of the answer. So, when you talk about this or that strategy or policy you can't really do that without talking about farming in Canada, which is still really big business, and how far the government of Canada is willing to go to support that (AAFC Employee 1).

Canada's national biotechnology strategy may be traced back to the 1980s when the federal Ministry of State for Science and Technology published the *Biotechnology in Canada* report and established a private sector task force initiating the promotion and development of biotechnology. The report outlined the potential of growing opportunities for R&D in biotechnology, but emphasized Canada's lack of expertise, educational programs, and industrial activity compared with that of the US and other countries in Europe. The report recommended that Canada focus on and develop key areas of biotechnology R&D including new plant technologies. Accordingly, the private sector task force outlined a 10-year plan to establish and grow various biotechnology industries. Essential elements of this plan were: a coordinated effort by the entire sector including the lead and catalyzing role of the government; industry incentives such as tax shelters and funding; developing the R&D infrastructure; increased international corroboration and enactment; and modification or elimination of regulation which inhibits Canada's competitiveness (MOSST, 1980).

These initiatives resulted in the establishment of the CBS and the National Biotechnology Advisory Committee (NBAC). The CBS was rooted in the late 1970s when a task force composed of industry and academia was established to determine how to facilitate the potential of new recombinant DNA techniques that were being developed. The CBS is Canada's plan for the emerging field of biotechnology that supports and compliments the regulatory and research activities of various federal departments and agencies and operates in a policy framework which defined the following objectives and principles:

> Ensure that Canadians have access to, confidence in and benefit from safe and effective biotechnology-based products and services; Ensure an effective scientific base and invest strategically in research and development; Position Canada as a responsible world leader in the development, commercialization, sale and use of biotechnology; Be sensitive to the needs of developing countries to build local capacity in managing the potential risks of biotechnology. Improve public awareness and understanding of biotechnology; … Promote awareness of and maintain excellence in Canada's regulatory system; … Support the development of human resources in the sector; and Work with the provinces, territories, businesses, academia and consumer and other groups to develop and carry out action plans (Health Canada, 2005).

The objectives and principles were premised on biotechnology having transformative potential. Accordingly, two issues have dominated the debates over the impact of biotechnology: first is the potential creative impact as biotechnology opens up new avenues for economic growth and employment; and second, the potential disruptive impact on society, social norms, and existing economic practices. While the growth potential of biotechnology made it an attractive sight for government activity, the potential controversies over biotechnological applications produced ongoing concerns regarding political responsibility (Sharaput, 2008).

In addition to the CBS initiatives, biotechnology brought together a wide array of ministries and governmental agencies with Industry Canada emerging as the lead trans-ministerial coordinator. Among the number of initiatives involving biotechnology were: the Canadian Foundation for Innovation (CFI); the Canadian Institutes of Health

Research; the Genomics R&D initiative; Genome Canada; Canadian Regulatory System for Biotechnology; Smart Regulations; and the Biotechnology Regulatory Framework. These federal government initiatives directly fund R&D efforts. For example, the Canadian Regulatory System for Biotechnology initiative ($35 million per year) and the Genomics R&D initiative ($20 million per year) (Government of Canada, 2011). An employee from Health Canada in an interview commented on the significant costs associated with genetic R&D and policy implementation.

> One of our priorities has always been this highest standards of safety in the world. For this reason the spending on the development of biotechnology has been substantial. Just the cost of infrastructure for R&D itself is substantial. The government has literally spent billions, but this is what it takes to get a project like this off the ground. This has of course been done in conjunction with industry, universities, health groups, and all kinds of organizations across Canada. We knew that if we get it right there would be great social and economic benefits down the line (Health Canada Employee).

A key element of the CBS was the establishment of the NBAC which consisted of multidisciplinary experts and members of the general public including representatives from academia, the private sector, and government. The mandate of the committee was the formulation of the government's biotechnology program which included: substantially greater financial investments in developing a science-base and technology transfer; remaining competitive on the global market; tax incentives and financial assistance for industry; legislation including IP laws that favour the industry; and improved collaborative efforts between Canada and the international community (Abergel and Barrett, 2002). In 1983, the National Biotechnology Strategy (NBS) was established to develop biotechnology in order to enhance economic, health, and environmental benefits to Canada. The NBS was renewed in 1998 after extensive consultation with provincial governments, industry, non-government organizations (NGOs), scientific and academic institutes, and other partners. Components of the NBS included: management structure and governance; an advisory committee; the framework underpinning the strategy; and mechanisms to facilitate the evolution of biotechnology towards refining a science-based regulatory system, commercialization, and social acceptance (Health Canada, 2005).

Innovation featured prominently as a policy goal throughout the 1980s and was strengthened by the science and technology policy InnovAction that was introduced in 1987. This policy entailed a substantial spending program that included: improving technological innovation and diffusion; developing 'strategic' technologies; assuring a highly trained workforce; support for basic and applied research; controlling the effects of technology on society; and promoting a 'science culture'. Public policy can influence innovation through a variety of policy instruments such as a stable economic environment aided by tax incentives for industrial research, monetary policy, direct subsidies for R&D, trade policy, regulatory frameworks and standards, and IP rights. Government innovation programs can involve creating a scientific and technological infrastructure that includes universities, research centers, government departments, educational and training institutions, financial institutions, and information network centers. By drawing on these instruments the Science Council of Canada directed attention to the importance of integrating technology into modern industrial processes. This entailed long-term restructuring of the economy, increased cooperation between the government and the private sector, and the strengthening of Canada's technological capabilities by focusing on additional key areas to biotechnology such as engineering and computer technology (Abergel and Barrett, 2002). Describing some of the tensions surrounding biotechnology in Canada, an employee from AAFC commented about the efforts by multiple Canadian government agencies for implementing policies that would strengthen the Canadian industry.

> The policies that were put in place in many ways were used to help secure the development of biotechnology. There was a lot of controversy about biotechnology and quite frankly much of it was nonsense. We were trying to position ourselves to make sure that we could meet any current and future challenges. We knew, based on a lot of scientific studies, that GM was safe. We also knew that we wanted to strengthen Canada's position in terms of our own contributions to agriculture and biotechnology. There was a lot of work to be done and a kind of re-making of the industry as novel technologies were being introduced. We wanted to move forward and figure how we could get GM foods into the market because this was in the best interest of Canadians. There were a lot of people on-board with this, like Health Canada, and Industry Canada, so it wasn't just Agriculture and Agri-Food Canada. There were also other groups that were involved from the public including NGOs and there were consultations that were held, but sometimes regardless of what you do you always have people that are going to assume that the entire project was shoved down people's throats, but it was not. I think you would agree that when you look at the outcome today, you will quickly learn that the project has been a great success (AAFC Employee 2).

Canada's biotechnology strategy and policy initiatives have been substantiated by significant federal government expenditures on biotechnology R&D more specifically (see Table 4.1) and science and technology R&D more generally (see Table 4.2).

Table 4.1: Annual Federal Government Science and Technology R&D on Biotechnology Expenditures

Year	**Amount** (thousands of dollars)
2003/2004	756,239
2004/2005	804,161
2005/2006	864,830
2006/2007	880,087
2007/2008	920,548
2008/2009	936,827

Notes and sources: this table contains the most current data available from Statistics Canada on biotechnology R&D expenditures. Disaggregated data following 2008/2009 is not available, (Statistics Canada, 2010, 2012b).

Table 4.2: Annual Federal Government Science and Technology R&D and Related Activities Expenditures

Year	**Amount** (millions of dollars)
2003/2004	8,765
2004/2005	8,934
2005/2006	9,449
2006/2007	9,633
2007/2008	10,176
2008/2009	10,573
2009/2010	11,614
2010/2011	12,014
2011/2012	11,395
2012/2013	11,166
2013/2014	10,868
2014/2015	10,281

Source: Statistics Canada, 2014b

In summary, the federal government of Canada has evinced a sense of technological optimism backed by substantial funding and tax credits for industrial R&D innovation going back to the 1960s. Amidst economic recession and lagging manufacturing throughout the 1970s and 1980s, the federal Government of Canada began to promote and develop biotechnology in part as an attempt at stimulating the national economy and international competitiveness through innovative, research-intensive, high-technology industries. The publication of the *Biotechnology in Canada* report and the establishment of the CBS and the NABC, among other initiatives, set the course for the establishment and growth of various biotechnology industries. The federal government established a policy structure that can influence innovation through a variety of instruments such as a stable economic environment aided by tax incentives for industrial research, monetary policy, direct subsidies for R&D, trade policy, regulatory frameworks and standards, and IP rights. Canada's innovation in biotechnology was regarded as part of the necessary adaptation and change which characterizes the essence of the capitalist production site.

4.2.2 Canadian Agricultural Biotechnology Regulation

Canadian regulatory agencies have attempted to develop regulatory practices that are rigorous but not restrictive so that agricultural biotechnology products may be used without adversely harming humans, animals, and the environment, while simultaneously not delaying or restricting industry competitiveness. The Government of Canada's efforts, however, have not taken place in isolation but have been influenced by the scientific community, NGOs, trading partners (the US and other OECD member countries), international organizations, and the biotechnology industry. The foundation of Canada's regulatory framework has been shaped by several regulatory documents from international organizations including: the OECD, the National Academy of Sciences, the FAO, and the World Health Organization (WHO). For example, in 1986, the OECD published the *Recombinant DNA Safety Considerations*, which provided guidance in the form of a set of recommended requirements for biotechnology products. This proved to be an important document, used by many countries including Canada, to develop their regulatory framework (OECD, 1986). The follow-up document, *Safety Considerations for Biotechnology* outlined safety assessment requirements especially related to environmental issues (OECD, 1992).

Among other things, these regulatory documents introduced and developed the principles of ‘familiarity’ (in reference to environmental release) and ‘substantial equivalence’ (in reference to food safety) which became central to the Canadian regulatory framework. The concepts of familiarity and substantial equivalence were premised on the notion that organisms developed through recombinant DNA techniques are not inherently different from organisms developed through other methods of genetic alteration (including, for example, natural mutation). Following from this perspective, the claim is made that GM products using recombinant DNA do not pose unique hazards and do not require distinctive risk assessment procedures. Any potential environmental impacts are expected to be similar to those that have been observed with the introduction of naturally occurring species or selected species used for agricultural applications (Abergel and Barrett, 2002).

The concepts of familiarity and substantial equivalence provided a ‘science-based’ rationale for streamlining the regulatory process. In 1988, the AAFC began accepting applications to conduct Canada’s first confined research field trials for plants with novel traits. AAFC was responsible for testing and registration of new plant cultivars under the *Seeds Act*. As such, AAFC fostered the required expertise in agriculture, agronomy, and biology to evaluate plants with novel traits. On assuming this new regulatory responsibility, AAFC conducted a number of multi-stakeholder consultations to seek advice on the scope and approach of its regulatory framework. For example, in 1988 the Canadian Agri-Food Research Council (CARC) held a workshop for Canadian scientists on the regulation of agricultural biotechnology. CARC is a non-profit consortium of researchers from industry, academia, and federal and provincial governments. As a result of this workshop, a product-based (i.e., genetic trait based), rather than process-based (i.e., technology used to develop the product), trigger for safety assessments of novel agricultural products was recommended to the Government of Canada. Also in 1988, the *Canadian Environmental Protection Act* (CEPA) was enacted with a requirement for regulatory review, adding a further level of guidance federally. CEPA identified that any person wanting to import, manufacture or sell a new product must notify the appropriate Canadian regulatory authority so the product could be evaluated for potential effects on the environment and human health (CFIA, 2007).

Given these efforts, among others, by the end of the 1980s the Government of Canada had succeeded in producing a regulatory framework based on the following principles: first, to build on current legislation where possible, rather than creating new legislation to govern new products which are developed. Second, to focus on product characteristics, rather than the method of production. All products developed through genetic engineering are assessed for unintended effects that may result from the introduction of foreign genes or DNA sequences. Third, to conduct evaluations for each product on the basis of its unique characteristics and to establish appropriate safety levels based on the best scientific information. Safety is defined, not as the complete absence of risk, but as the level of acceptable risk.

In addition, the Government of Canada supported efforts towards harmonizing regulatory efforts with those of trading partners such as the US and other OECD member countries, recognizing that continued export of agricultural and other products and the removal of trade barriers depended on mutually consistent standards of safety and regulatory oversight. Accordingly, the Government of Canada participated in the OECD Working Group on Harmonization of Regulatory Oversight in Biotechnology and the Taskforce for the Safety of Novel Foods and Feeds. The primary focus of these groups was to develop consistent regulations among member countries while avoiding trade barriers. Membership in international organizations helps to exchange expertise and facilitate access to current scientific and regulatory information regarding safety assessments of novel agricultural products at the international scale. The Government of Canada was also interested in bilateral initiatives with other countries. For example, Canada and the US have harmonized their data requirements for molecular characterization data (the detailed information describing the genetic makeup of an organism) of the regulatory review process for plants with novel traits. At the national scale, the CFIA and Health Canada have adopted a policy of concurrent approvals (i.e., required assessments for all uses are completed at approximately the same time) to minimize the potential for unapproved plants with novel traits, novel livestock feeds, and/or novel foods to enter into the Canadian environment, livestock feed and/or food supply (CFIA, 2007).

Despite previous attempts throughout the 1980s to establish a regulatory framework for biotechnology, in 1993, the Government of Canada produced a new biotechnology regulatory framework entitled *Federal Regulatory Framework for Biotechnology*. This framework resulted from an agreement among federal regulatory departments on principles for an efficient and effective approach for regulating biotechnology. The framework was based on the following principles:

> maintains Canada's high standards for the protection of the health of workers, the general public, and the environment; uses existing legislation and regulatory institutions to clarify responsibilities and avoid duplication; continues to develop clear novel product evaluation guidelines that are harmonized with national priorities and international standards; provides a sound scientific database on which to assess risk and evaluate products; ensures transparent and consultative development and enforcement of Canadian biotechnology regulations; [and] contributes to the prosperity and well being of Canadians by fostering a favourable climate for investment, development, innovation, and adoption of sustainable Canadian biotechnology products and processes (CFIA, 2007, 13).

Currently, several agencies in Canada are involved in the regulation of agricultural products. For example, the CFIA is the lead agency responsible for regulation under the jurisdiction of, among others, the *Health of Animals Act*, the *Plant Protection Act*, the *Seeds Act*, the *Fertilizers Act*, and the *Feeds Act*. The CFIA is responsible for regulating both the efficacy and the environmental safety of the product in question. Regulations clearly describe how the CFIA will conduct environmental assessments of agricultural biotechnology products. Also, the CFIA is responsible for inspection and monitoring so that registered products continue to meet quality and safety standards after their approval. Lastly, the CFIA is responsible for non-safety related product labelling (e.g., voluntary labelling, consumer fraud issues). Health Canada, under the jurisdiction of the *Food and Drugs Act*, has primary responsibility for human health related issues. Health Canada is responsible for setting standards for safety of the food supply, including biotechnology food products (novel foods). Their *Guidelines for the Safety Assessment of Novel Foods* outline the criteria they consider in making an assessment of the safety to human health from GM microorganisms and plants. Also, Health Canada is responsible for required labelling related to health and safety issues (e.g., allergenicity, changes in nutritional composition) (CFIA, 2014) (see Table 4.3).

Table 4.3: Agricultural Products, Legislation and Regulatory Control, with Particular Emphasis on Novel Agricultural Products Grown Domestically

Department/ Agency	**Products Regulated**	**Relevant Legislation**	**Regulations**
Canadian Food Inspection Agency (CFIA)	Plants and seeds, including those with novel traits, Animals, Animals vaccines and biologics, Fertilizers, Livestock feeds	*Consumer Packaging and Labeling Act,* *Feeds Act,* *Fertilizer Act,* *Food and Drugs Act,* *Health of Animals Act,* *Seeds Act,* *Plant Protection Act*	*Feeds Regulations,* *Fertilizer Regulations,* *Health of Animals Regulations,* *Food and Drug Regulations*
Environment Canada (EC)	Biotechnology products under CEPA, such as microorganisms used in bioremediation, Waste disposal, mineral leaching or enhanced oil recovery	*Canadian Environmental Protection Act* (CEPA)	*New Substances Notification Regulations* (These regulations apply to products not regulated under other federal legislation)
Health Canada (HC)	Foods, Drugs, Cosmetics, Medical devices, Pest control products	*Food and Drugs Act,* *Canadian Environmental Protection Act,* *Pest Control Products Act*	*Cosmetics Regulations,* *Food and Drug Regulations,* *Novel Foods Regulations,* *Medical Devices Regulations,*

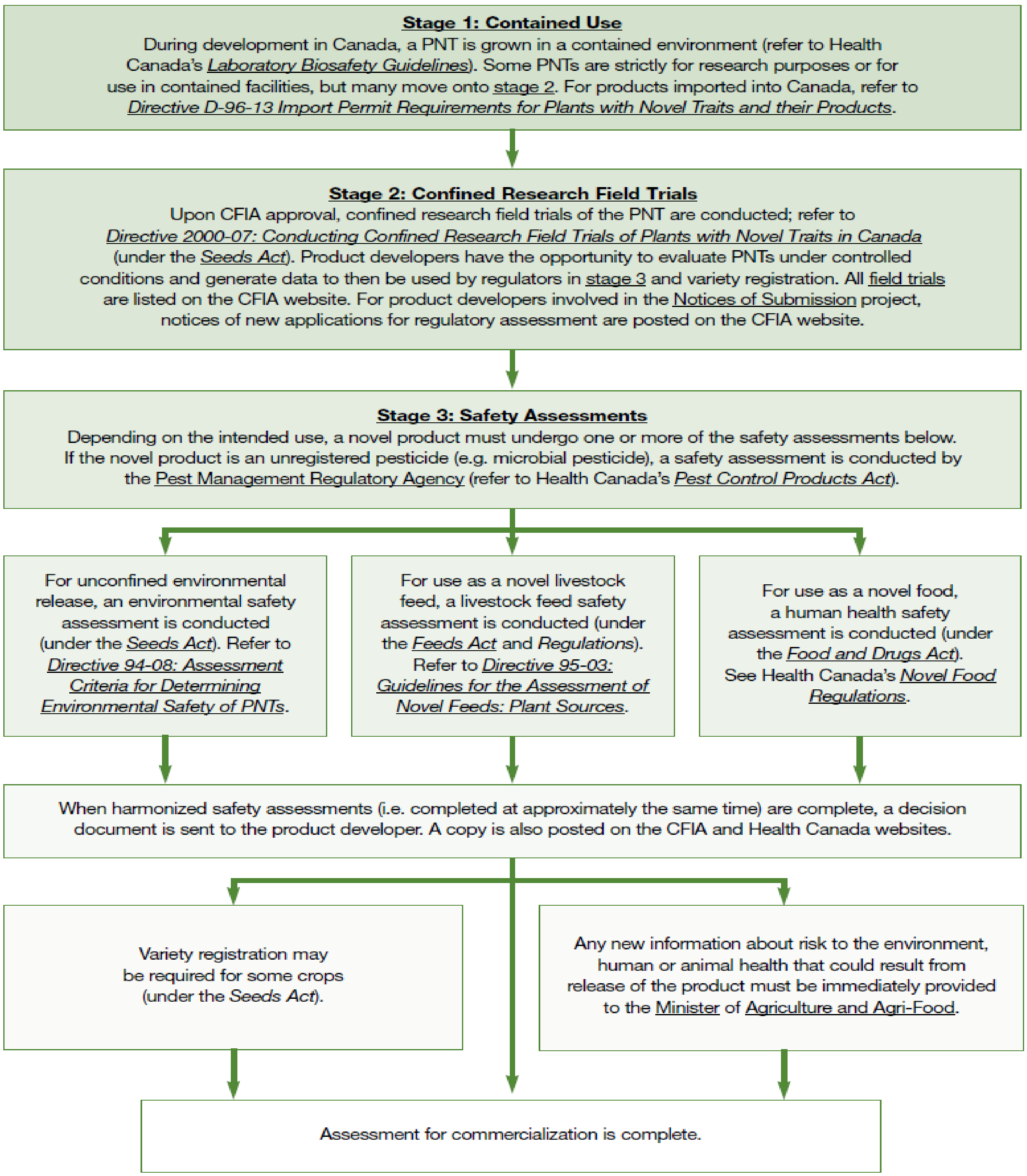
			New Substances Notification Regulations, Pest Control Products Regulation
Fisheries and Oceans Canada	Potential environmental release of transgenic aquatic organisms	*Fisheries Act*	Under development

Source: CFIA, 2007, 11

There is a vast array of agricultural products being developed or imported into Canada. Depending on the type of product, where it comes from and the intended use, different control measures are used. All potentially hazardous imported commodities are controlled to reduce the possibility of the introduction of agricultural pests and diseases. Examples of such controls include the use of permits, testing, quarantine or inspection. Products which may pose a hazard to the environment are subjected to an environmental safety assessment. All new products produced by conventional means or derived through genetic engineering are included in this category. Government evaluators, in collaboration with experts and the public, have developed guidelines for each class of domestically-produced product, which assist in the development of new products in the research stage. These regulatory directives facilitate the presentation of adequate and appropriate information by the product developer, so that potential hazards can be identified early in the process. Government regulators use this information to determine whether or not new products meet acceptable safety standards (CFIA, 2014).

Based on the product definition, specified protocols are applied which govern the conditions of release into the environment. Frequently, field testing is performed on a confined basis. In certain cases, such as for contract growing, certain confinement conditions may be either imposed or relaxed depending on the characteristics of a novel product. Scientific information is gathered during the development phase, and provided to evaluators as required. Information is produced during research trials conducted under laboratory conditions and field testing of new plants, or, in the case of veterinary biologics and livestock feeds, animal testing. Depending on the product, prior to commercial production, approval, registration or licensing may be required. This is done in the case of bio-fertilizers, certain plant species, livestock feeds, and veterinary biologics. Once the product has been approved, quality assurance monitoring of the products, as in the case of veterinary biologics, or food safety inspection, will be performed. All of these regulatory control measures are taken to assess the quality, safety and efficacy of the product (CFIA, 2014) (see Table 4.4).

Table 4.4: Regulation of Plants with Novel Traits and/or Novel Livestock Feeds Derived from Plants in Canada



Source: CFIA, 2007, 19

These developments may be understood in light of what some authors have referred to as a transnational biotech bloc. For example, Eaton (2013, 33) noted,

> Buying into the rhetoric and material promises of the transnational biotech bloc, Canada has promoted biotechnology from the beginning as a strategy for economic development and international competitiveness. Regulations, international property rights, and international trade have been fashioned around the needs of the biotech industry, with private interests increasingly determining the nature of the Canadian's state engagement with the technology. Indeed the development of the biotech industry in Canada happened alongside a policy change that saw federal agricultural research move from relative autonomy toward increasing engagement with public-private partnerships and industry-driven research agendas and funding. Before consulting the public or developing a regulatory structure for the approval of GMOs, the Canadian state had already enrolled in the transnational biotech bloc.

An AAFC employee in an interview commented about the Government of Canada's various attempts at regulating biotechnology in a manner that is conducive to broader concerns about integration and harmonization with international protocols aimed at market penetration.

> There wasn't much clarity back then about how we were going to regulate GM products. New plant varieties and seeds produced using genetic modification would be covered under the *Seeds Act* and administered by Agriculture Canada at that time which is now Agriculture and Agri-Food Canada. There was also talk about Environment Canada under the CEPA [*Canadian Environmental Protection Act*] regulating biotechnology products, which would then subject biotech products to environmental assessment by Environment Canada. Things were moving quickly though and there was the sense that we shouldn't do anything to inhibit getting the technology out into the market. Regulation should be more about facilitating the process. The Government of Canada was not alone in this. We were very much part of the regulatory framework that was being developed in the US and by the OECD. There was a push to harmonize with other countries so that everyone is on the same playing field. This was not just about health and the environment, there was also this whole commerce push and reducing international barriers to trade. Canada of course supported all this because we recognized the importance of harmonizing for the sake of continued export of agricultural products. Eventually regulation remained under the mandate of Agriculture and

> Agri-Food Canada and Environment Canada and the CEPA would play a safety-net role covering products not already regulated by the existing legislation (AAFC Employee 3).

To summarize, Canadian regulatory agencies developed regulatory practices in conjunction with the scientific community, NGOs, trading partners, international organizations, and the biotechnology industry that provided a 'science-based' rationale for streamlining the regulatory process. These developments have been fashioned around the biotechnology industry through an on-going engagement in private-public partnerships and industry driven research agendas and funding, and have been embedded into a nexus of relevant trade agreements that insure globally advantageous terms for advanced capitalist states and the corporations active in their national jurisdictions. Indeed, the Canadian state has become a major player in the transnational biotech bloc.

4.3 Market Impact of the Canadian Agricultural Biotechnology Industry

By the mid-1990s, a concerted campaign based on aggressive corporate mergers and acquisitions as well as partnerships among the largest multinational corporations in agricultural biotechnology was taking place. In 1996, the top 11 seed companies: Monsanto (US), DuPont (US), Syngenta (Switzerland), Groupe Limagrain (France), Land O'Lakes (US), KWS SAAT SE (Germany), Bayer (Germany), Dow (US), Sakata (Japan), DLF-Trifolium (Denmark), and Takii (Japan) accounted for 37% of the world's seed market. Moreover, within a short decade since its shift to agricultural biotechnology in the 1980s, Monsanto emerged as the largest player in the industry (Peekhaus, 2013). Following vigorous marketing in Canada of GM canola, GM soybean, and GM corn (the three largest GM crops cultivated in Canada), Monsanto received regulatory approval from Health Canada to market glyphosate tolerant canola for food use in 1994 and glyphosate tolerant soybean in 1996. The glyphosate tolerant seeds, marketed as 'Roundup Ready', are genetically engineered to produce crops capable of surviving post-emergent applications of 'Roundup', a broad-spectrum non selective systemic herbicide that is sprayed and absorbed through the leaves of the plants (Health Canada, 2000). Monsanto's insect resistant corn received regulatory approval from Health Canada to market for food use in 1997 (Health Canada, 1997).

From 1994 to 2014, Health Canada approved 184 novel foods (Health Canada, 2015). In 2014, the top holder of approved novel food decisions among the top 24 firms in Canada was Monsanto with 39, followed by BASF with 17, and Pioneer with 13. Private sector firms held 181 or 98% of approved novel food decisions, AAFC held 1, the University of Saskatchewan held 1, and the University of British Columbia held 1 (Health Canada, 2015). Four GM crops are grown in Canada: canola, corn, soybean, and sugar beet (see Table 4.5).

Table 4.5: Canadian Area of Conventional and GM Crops in Thousands of Hectares by Crop from 2007 to 2012

Crop Area (hectares in thousands)	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Corn for grain	1,391.50	1,204.00	1,203.50	1,214.30	1,217.70	1,472.40
Fodder corn	246.4	244.9	312.2	244.6	205.9	230.7
Total corn	1,637.90	1,448.90	1,515.70	1,458.90	1,423.60	1,703.10
GM corn	636.7	632.6	743	795.1	811.3	1,201.40
GM corn as percent of total	39	44	49	54	57	71
Soybean	1,180.10	1,211.30	1,395.30	1,483.00	1,549.90	1,746.50
GM soybean	529.7	604.7	604.6	658.1	742.3	1,130.10

GM soybean as percent of total	45	50	43	44	48	65
Canola	5,959.50	6,398.90	6,555.80	6,806.10	7,633.20	8,608.70
GM canola	4,767.60	5,119.10	5,244.60	5,444.90	6,106.60	8,178.30
GM canola as percent of total	80	80	80	80	80	95

Source: Evans and Lupescu, 2012

GM sugar beet has been planted in Canada since 2008. Production is concentrated in Taber, Alberta where Canada's only sugar beet processing plant is located. In 2010, 96% of the sugar beet crop (approximately 13,000 ha) was GM sugar beet (Evans and Lupescu, 2012). Currently, I am not aware of any published analysis of the economic impact of GM sugar beet in Canada.

Most of Canada's canola production is centered in the western provinces of Manitoba, Saskatchewan, and Alberta. Approximately 15% of the Canadian canola crop is consumed in Canada in various forms. The remainder 85% of canola seed, oil, and meal are exported to destinations such as the US, Japan, Mexico, and China (Evans and Lupescu, 2012). The commercialization of herb-tolerant canola began in 1996 and by 2014 farmers planted 8 million hectares accounting for 95% of all the canola grown in Canada and 69% of all GM crops.

The overall impact on profitability from adopting GM canola (inclusive of yield improvements and higher quality) has been an increase of between $22/ha and $74/ha. The annual total national farm income benefit from using the technology has risen from $6 million in 1996 to $404 million in 2011 (Brookes and Barfoot, 2013).

GM corn has also been grown commercially in Canada since 1996. In 2011 it accounted for 70% of the 1.2 million ha of corn grown in Canada. Traditionally, Quebec and Ontario are the primary corn-growing regions, accounting for 86% of total Canadian corn. In Quebec, 74% of the total corn crop was GM corn in 2012, up from 47 percent in 2007, while in Ontario 75% of the total corn crop was GM corn in 2012, up from 41 percent in 2007. More recently there has also been an upward trend in the planting of GM corn in Manitoba (Evans and Lupescu, 2012). The additional farm income generated from the use of GM corn at the national level was $116 million in 2011 and cumulatively $694.4 million since 1996 (Brookes and Barfoot, 2013).

GM soybean was first planted in Canada in 1997. Traditionally, Quebec and Ontario have been the primary soybean growing regions in Canada, accounting for 92% of total soybean acreage in 2007. With the rise of Manitoba as a soybean producing province, the combined share for Quebec and Ontario has slowly declined over time. In 2012, Ontario and Quebec accounted for approximately 78% of total soybean acreage, while Manitoba's share increased from 8% in 2007 to 20% in 2012 (Evans and Lupescu, 2012). The average farm income benefit has been between $14/ha and $40/ha and the increase in farm income at the national level was $12.3 million in 2011. The cumulative increase in farm income since 1997 has been $155.5 million (Brookes and Barfoot, 2013). Canadian grain exports demonstrate a general increase in the number of metric tonnes exported of the three major GM crops from 2005/2006 to 2014/2015 (see Table 4.6).

Table 4.6: Canadian Exports of Canola, Corn, and Soybean from Licensed Facilities for the Crop Years 2005/2006 to 2014/2015 in Thousands of Metric Tonnes

	2005-2006	**2006-2007**	**2007-2008**	**2008-2009**	**2009-2010**	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**
Canola	5308.8	5466.4	5594.2	7842	7245.1	7032.3	8580.3	7165	8628	8897.8
Corn	164.4	193.3	577	146.4	32.6	1264.3	73.7	605	1760	271.2
Soybeans	832	1028.5	1009.2	1236.1	1197.4	2035.4	1964.3	2550.9	2405.5	2424.4

Source: CGC, 2015

In addition to plants with novel traits (crops and horticultural plants), the agriculture and agro-food sector in Canada uses biotechnology in a variety of ways to produce agricultural inputs and food products including: veterinary drugs and biologics (drugs used for the treatment or diagnosis of infectious diseases of animals); bio-pesticides (for insect, disease, and pest control); novel fertilizer supplements or bio-fertilizers (to improve plant growth); livestock feed and feed additives; and novel foods (CFIA, 2014). The data presented in this section confirm that the on-going promotion and funding of agricultural biotechnology by the Government of Canada has made a significant market impact on the Canadian agriculture and agro-food sector.

4.4 Rising Contestations

Public opposition to genetic engineering may be traced back to the US in the early 1980s when proposals were made to release organisms deliberately for field testing (Krimsky, 1991) following which environmental organizations began to enter the debate (Goldburg et al., 1990). Also, in the mid-1980s controversy began to erupt inside the scientific community over issues such as gene transfer, the evolution of weed and insect resistance to modified traits, socio-economic impacts, among other issues (see Colwell et al., 1985; Halvorson et al., 1985). By the late 1980s, tensions began to erupt in Canada as “a growing number of activists, NGOs, and scientists began voicing concerns about the potential ethical, environmental, social, and health risks associated with GMOs” (Eaton, 2013, 33). An activist with Greenpeace Canada in an interview commented on the shortcomings of regulatory practices that are based on the concepts of familiarity and substantial equivalence, the growing resistance by many activists against such practices, and the Government of Canada's implementation of these polices despite on-going resistance.

> The entire thing [regulatory process] was flawed right from the beginning, as far as I'm concerned. The government has never given any kind of special treatment to biotechnology products, but lumped them in there under the regulation of other agricultural products. How can you do that? How can a regulatory system designed around traditional agriculture all of a sudden be used for biotech agriculture? This was part of the plan of getting the products into the market as fast as possible and prevent any kind of lengthy assessments which of course are not great for business and supporting the industry. The government made sure that nothing would come in the way of the industry profiting despite any other issues that may arise. Many of us really fought this under CEPA [*Canadian Environmental Protection Act*] and demanded a more comprehensive regulatory framework that encompasses biotechnology, but the government decided that the legislation in agriculture and health is sufficient. What was interesting about this whole thing is that the government not only was protecting the industry against any kind of stringent regulations, perhaps out of fear that what happened to the industry in Europe may end up happening here, but also entrenching this crazy idea that genetic products are no different than products produced using natural processes. Anyways, the government and industry had an agenda and nothing was going to stop them (Greenpeace Canada Activist 1).

Given these controversies, a series of meetings were organized in 1993 that included representatives from government, academia, NGOs, and industry. While the purpose of the meetings at first appeared to be an effort towards more diverse debates around biotechnology, in reality they were predominantly confined around discussions about 'science-based' approaches to regulation and the economic advantages of adopting biotechnology. According to Abergel and Barrett (2002), representatives from consumer and environmental organizations cited restricted access to information, inappropriate extraction of existing legislation, lack of public participation and debate, and failure to address ethical issues. Representatives from government and industry stressed the importance of a competitive regulatory framework, the potential costs of over-regulation, and the need to harmonize policies with international traders.

Following the 1993 meetings, branches of the Government of Canada produced documents and held consultations that emphasized the need to moderate the drive towards biotechnological innovation with considerations of the social, economic, political, environmental, and ethical dimensions. For example, in 1994, the report from the Standing Committee on Agriculture and Agri-Food urged decision-makers to consider socio-economic and environmental effects in their assessment of GMOs. In 1996, the Committee on Environment and Sustainable Development stated that current regulatory frameworks inadequately addressed recombinant DNA technology. In 1998, a NBAC report emphasized the importance of fostering public awareness, input, and consideration of the social-ethical dimensions of biotechnology (Abergel and Barrett, 2002).

The most critical assessment of the Government of Canada's biotechnology regulatory framework came in 2001 from the RSC's Expert Panel Report on the Future of Food Biotechnology entitled *Elements of Precaution: Recommendations for the Regulation of Food Biotechnology in Canada* at the request of Health Canada, the CFIA, and Environment Canada. The panel consisted of 14 experts from a variety of fields including: botany, philosophy, law, biotechnology, paediatrics, biology, toxicology, and animal science. The purpose of the panel was to provide advice on the Canadian regulatory system and the scientific capacity the federal government required to ensure the safety of new food products being developed through biotechnology. The panel summarized the scientific developments that led to the current status of application of the technology and identified the social and scientific dynamics that foreshadow new applications of biotechnology. It examined in detail the safety implications of these applications for human and animal health and the environment. The panel also critically examined the standard principles and practices governing the regulation of food biotechnology both in Canada and internationally, and made a series of recommendations in three areas: first, those concerning fundamental policies and principles governing the regulation of biotechnology; second, those concerning specific Canadian regulations and guidelines; and third, those concerning the regulatory process itself (RSC, 2001). These recommendations were based on the globally accepted precautionary approach to risk assessment developed at the Rio Conference in 1992. Two ideas lie at the core of the precautionary approach: first, an expression of a need by decision-makers to anticipate harm before it occurs. Within this element lies an implicit reversal of the onus of proof. Under the precautionary approach it is the responsibility of an activity proponent to establish that the proposed activity will not (or is very unlikely to) result in significant harm. Second, the concept of proportionality of the risk and the cost and feasibility of a proposed action (Jordan and O'Riordan, 2004).

At issue was the adoption of the controversial concepts of familiarity and substantial equivalence as foundational principles in the formation of the Canadian regulatory framework. The panel challenged the validity of a linear model of scientific assessment arguing that equivalence claims cannot be made *a priori*; rather, an integrated approach of rigorous scientific evaluation is required to uncover how phenotypes are affected by genomes and their variants at multiple levels. The panel found "the use of "substantial equivalence" as a decision threshold tool to exempt GM agricultural products from rigorous scientific assessment to be scientifically unjustifiable and inconsistent with precautionary regulation of the technology. The Panel recommends a four-stage [DNA structure, gene expression, protein profiling, and metabolic profiling] diagnostic assessment of transgenic crops and foods that would replace current regulatory reliance upon "substantial equivalence" as a decision threshold" (RSC, 2001, ix). This perspective found resonance among other researchers as well. For example, Millstone et al. (1999, 526) claimed that substantial equivalence is a "pseudo-scientific" concept that is "inherently ant-scientific" created primarily as "an excuse for not requiring biochemical or toxicological tests".

Also, the panel was critical of the government and industry's claim that the regulatory process was 'science-based'. In particular, three issues were raised: first, ethical concerns about the government's reliance on scientific research and data supplied by the same corporations seeking regulatory approval for their products. Second, the government and industry refusing experts in the field free access to data for scientific review including independent evaluation of the data or the statistical validity of the experimental design used to collect the data. Third, a lack of transparency and information sharing leading to inability to assess the scientific rigour in current approval processes. Although these outcomes contradict the Canadian Biotechnology Strategy's emphasis on science-based technical assessment methodologies in the regulatory framework, it was fitting given the context of rapid technological development by large economies of scale where a handful of multinational corporations play national economies against each other for favourable market conditions. This makes a case for rendering the Government of Canada's regulatory and marketplace framework conducive to private sector investment and commercialization. A regulatory system increasingly stacked in favour of industry interests, as implicitly admitted by government policy, accounts for the conflict of interest and informational gaps in Canada's regulatory regime. This essentially placed the regulator and the industry in the same playing field and raised issues regarding industry capture by state regulators (Peekhaus, 2013). An activist from the CBAN commented on the controversial nature of the regulatory process, where regulation primarily serves the interests of the industry rather than that of the public. This conflict of interest has undermined the role of Government of Canada as both regulator and promoter of agricultural biotechnology products.

> Basically what we have here is the Government of Canada's dual role as a regulator and promoter of biotechnology, and what you end up with is a situation where the regulation is meeting the interests of the industry instead of doing what regulation is supposed to do in the first place, which is protect the interest of the public. Part of the problem with this scenario is that regulatory agencies in Canada have to establish a working relationship with the industry, and once you do that then it becomes very difficult to remain objective. This to a great degree has undermined the government's credibility; really, we don't know what to think sometimes about what is going on in the CFIA and how much we can trust and what they're telling us about biotechnology, and especially the foods we are consuming in some cases on a daily basis. One indication of these tensions is that there are all kinds of criticisms coming including things like the RSC report, and other experts from Health Canada for example. There was a petition that came out some time ago from federal government bureaucrats, you know, saying there's a serious conflict of interest here when the products you are regulating are the same products you are promoting. There was also the case where Shiv Chopra and a bunch of his colleagues from Health Canada were fired because they refused to sign off on regulatory applications because they believed the products were dangerous for human and animal health. I mean this is the kind of crazy stuff that's happening all in the name of big business (CBAN Activist 1).

In response, the Government of Canada published an action plan and accompanying progress reports (see, for example, Government of Canada, 2001;

Health Canada, 2013) in which the government made commitments to: revise relevant documents and create new information materials explaining the regulatory system to the public; update and refine protocols for the CFIA's safety assessment as science progresses and more advanced methods become available; participate in international efforts and seek contributions from experts to develop and validate testing protocols and other tools to address biotechnology issues; increase scientific and regulatory capacity with scientists trained in molecular biology, entomology, ecology, and other sciences related to plants, animals, and the environment; and support research projects relevant to biotechnology issues. Accordingly, in the spring of 2001, the CBAC held five consultations across Canada with industry stakeholders, academia, and civil society organizations to discuss the regulation of novel foods. The CFIA officials participated in each workshop to provide technical and regulatory information as required. The CBAC released an interim report in August 2001, and the CFIA officials met with the CBAC's members to comment on the report. The Canadian public was given until January 2002 to provide comments. The CBAC's full report was released in August 2002 entitled *Improving the Regulation of Genetically Modified Foods and Other Novel Foods in Canada*. The report provided 44 recommendations for improving the regulation of novel foods that may be categorized under eight areas: structure, organization, and operation of the federal food regulatory system; transparency and public involvement; precautionary elements; evaluation and monitoring of long-term health impacts; environmental stewardship; improved information to support consumer choice; labelling; and other social and ethical considerations related to GM foods (CBAC, 2002).

Although the panel recommended a four-stage diagnostic assessment of transgenic crops and foods that would replace current regulatory reliance on substantial equivalence as a decision threshold, the CBAC's report embraced a combination of substantial equivalence and the precautionary principle in their criterion when assessing differences between conventional and genetically engineered food crops. The report stated,

> *Regulatory action in accord with the Precautionary Principle means the imposition of more "conservative" safety standards with respect to certain kinds of risks. Where there are health or environmental risks involving catastrophe scenarios (e.g. the potential effects of global warming), the greater the case for more conservative safety standards such as "zero-risk" or low threshold standards, such as that of "substantial equivalence", as articulated above. In the Panel's view, when "substantial equivalence" is invoked as an unambiguous safety standard (and not as a decision threshold for risk assessment) it stipulates a reasonably conservative standard of safety consistent with a precautionary approach to the regulations of risk associated with GM-foods* (CBAC, 2002, 15, italics in original).

An activist from the CBAN commented on the perfunctory aspect of the CBAC's consultations, following which, for the most part, little had changed in terms of rigorously assessing genetically engineered food products.

> The Canadian government was developing this new language around GM products like 'novel foods' and 'plants with novel traits' and it was all one way to hide the facts from the public about what was really happening with genetically engineered foods. The most problematic thing they were doing was using these supposedly 'science-based' concepts like 'familiarity' and 'substantial equivalence' and then they started talking about the 'precaution principle' which all sounded really great but quite seriously was nonsensical. Bottom line is, after all was said and done, any kind of real risks that have been documented by many scientists about GM foods are never sufficiently scrutinized in the Canadian regulation system. You know, according to their logic, there is nothing new under the sun when it comes to GM foods, which means there is no need for new regulations and no need to bother the public with talks about new risks. If you take any kind of independent studies seriously, you will

> quickly learn that the picture is not as clear as they claim it to be; I mean there are some serious issues with GM foods that need to be looked at (CBAN Activist 2).

Examining the CBAC's consultations between 1999-2003, Prudham and Morris (2006, 147) argued "that the CBAC GM foods project was, at best, a poorly conceived effort to engage with and respond to public concerns about GM foods, compromised by a prior commitment to commercialization. At worst, it was a cynical exercise coloured by a desire to secure and consolidate the legitimacy of GM foods in the midst of growing controversy". The authors link this to the CBAC's close ties with Industry Canada which resulted in discouraging many NGOs from participating in CBAC's public consultations, therefore limiting their efficacy, and the CBAC's recommendations which highly favoured the biotechnology industry. An activist from Greenpeace Canada who was involved in the CBAC's consultations commented in an interview that the consultations were not about addressing public concerns, rather they were an opportunity for the Government of Canada to further secure the success of the biotechnology industry, therefore undermining the imperative to deal democratically with public concerns while simultaneously supporting the profitability of the industry.

> Many of us basically boycotted the consultations. This may seem like a defeatist attitude, but really it isn't. By the time the government had setup the consultations it was clear that all the decisions were already made about which way Canada was heading in terms of the biotechnology project and the GM food issue. The consultations were a kind of façade to hide what was really going on. You give the impression that people have a choice, and then you setup a bunch of meetings to hear them out, but then whatever they say basically falls on deaf ears. I mean seriously, they call this a debate, but what debate? This may seem very cynical, but there was nothing we could do to change the course of action that was coming. Billions had already been spent, the CBAC was in the pocket of Industry Canada; there were corporations that were expecting support to move forward, and those of us who were questioning things like regulation

> and human and animal safety, and the rest of it, had to be appeased in some way. The government had to make it look like it really cares about what Canadians think, so the consultations were supposed to do that, but in reality it was business-as-usual, which was the case before the consultations started (Greenpeace Canada Activist 2).

To summarize, although the expected benefits from biotechnology were shared across ministerial boundaries, biotechnology became a subject of much public debate. Biotechnology was perceived not only as an opportunity, but also as a risk with social and economic consequences. Moreover, given the novelty of biotechnology, the public was unfamiliar with it. Consequently, while a particular ministry became involved in some aspect of biotechnology regulation, such as that of GM foods for example, it would quickly find itself drawn into debates over the social and ethical implications of such regulatory practices. Sharaput (2008, 259) stated, "[b]iotechnology policy's wide application, transformative potential, and extensive links to innovative and competitive strategies meant that it became recognized as a policy field for which ultimate responsibility was a reliability". This was due to the phases in the development of biotechnology policy. While initially biotechnology policy was primarily concerned with the development of basic R&D capacity followed by the focus on adapting such developments to commercial and innovative applications, it was not until much later that the regulation of the sector in accordance with emerging social and ethical concerns was taken into consideration (Sharaput, 2008).

The issues that were at the heart of the debate around biotechnology in Canada, and remain with us today, may be summarized in the following way: first has been the Government of Canada's insistence on defining the terms of the debate around 'sound science' and a 'science-based' approach that included treating genetically engineered products on the basis of the concepts of familiarity and substantial equivalence. Second has been the Government of Canada's consistent ruling out and/or undermining of the social, economic, political, environmental, human health, and ethical dimensions of biotechnology. Third has been the dual role that the Government of Canada adopted, on the one hand, as the assessor and regulator of all biological products developed and marketed for human and animal consumption and environmental release, and on the other hand, as the promoter and funder of agricultural biotechnology development and industry.

4.5 Conclusion

My analysis brings into focus the interrelationship among Canada's biotechnology strategy, policy implementation, and regulatory practices and the interventions by the state and civil society organizations in these processes. Capitalist states embedded in transnational networks promote value accumulation through policy implementation and regulatory practices geared at capturing competitive opportunities while simultaneously seeking to mediate the partial interests of civil society organizations, individual capitals, and the general reproduction demands of capital as a whole. The GM crops narrative is in part about the tension between compliant government structures and resistant civil society action seeking to partially counter the encroachment of the capitalist market.

The development, adoption, and production of agricultural biotechnology in the Canadian context is not only the result of the efforts of individual capitals, but also those of the Canadian state. This raises issues about the relationship of the state to, on the one hand, capitalist social relations, and on the other hand, science and technology.

Regarding the relationship of the state to capitalist social relations, an extensive debate exists in the Marxist literature (for reviews of this debate see, for example, Clarke, 1991a; Jessop, 1982). By virtue of its insertion into the structure of capitalist social relations, the state must promote value accumulation and reproduce the capitalist system. The social relations of capitalism require a regularized set of behaviours as well as the assurance of particular interaction between classes. The state continues to be the arbiter of that interaction and an entity which enforces an environment that is most amenable for the continuation of capitalist development. However, the particular form (e.g., policies and regulatory practices) the state implements and the outcomes are contingent on specific historical, geographical, and material conditions prevalent under capitalist social relations. Clarke (1991b, 168-169) noted, “The state does not constitute the social relations of production, it is essentially a regulative agency, whose analysis, therefore, presupposes the analysis of the social relations of which the state is regulative. The analysis of the capitalist state conceptually presupposes the analysis of capital and of the reproduction of capitalist relations of production, despite the fact that in reality, of course, the state is itself a moment of the process of reproduction”. The Government of Canada’s agricultural biotechnology policy, regulation, and funding regimes demonstrate the degree to which the economic is embedded in political structures of power as well as the reflexive nature of those political forms that depend in part on the economy for their continued existence.

Regarding the relationship of the state to science and technology, the Canadian state has been a critical non-economic actor in the drive toward agricultural biotechnology R&D aimed at commodity production. Interestingly, this is contrary to the neo-liberal rhetoric advanced since the 1980s about the state withdrawing from active participation in the economic markets and political regulation and control of advanced industrial capital (Harvey, 2005). In fact, the Government of Canada's agricultural biotechnology science and technology policy implementation, regulatory practices, and funding structures have become part of the general and external guarantees of the social conditions of production directed toward specific capitals as well as the sector as a whole. This demonstrates that in order for the state to ensure value accumulation and the reproduction of the capitalist system it must provide certain tangible, advantageous preconditions. The pursuit of growth policies necessitates an infrastructure that requires significant capital outlays which cannot be realized by individual capitals. Public policy is utilized to transfer social surplus value into particular sectors that not only give extra incentives to develop science and technology, but minimize the associated risks of venturing into such avenues (Hirsch, 1978; Loeppky, 2005). This is orchestrated, as has been discussed, in different ways, such as funding projects, tax relief incentives, infrastructure development, and so on. By accepting and promoting capitalist control over the development of biotechnology R&D, the Canadian state has been compelled to operate in ways that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

The state's involvement in science and technology represents a field in which particular groups can gain ascendancy while negotiating for the most advantageous policy. Indeed, the state can, against the will of many capitals, force the procurement of scientific and technological advance. Accordingly, state science and technology policy cannot be understood as the smooth reaction of the requirements of (re)production

(Hirsch, 1978), but by the partial interests of civil society, individual capitals, and the general reproduction demands of capital as a whole. The theoretical understanding of the state in relation to technology must, like all state functions, be mediated through the course and results of political (class) struggle. In this sense, not only is the examination of state policy an examination of fundamental social relations, but the specific case of agricultural biotechnology in Canada offers an illustration of its contradictory tendencies. In the face of the separation between the political and the economic, the state's ostensible 'neutral' mobilization is systematically pressed into the service of the partial interests of capital (Leoppky, 2005).

Moreover, civil society action has been effective, for example, by pressuring sub-national and national levels of authority to implement moratoria on the production and/or importation of GM crops and foods, and by directly challenging multinational corporations, the institutionalization of systems of private regulation, and the creation of new market categories (Hall and Moran, 2006; Harsh, 2014; Heller, 2006; King and Pearce, 2010; Schurman and Munro, 2009). In the Canadian case, the strong opposition to the adoption of GM wheat has illustrated the historical, political, and cultural significance of wheat farming, and its role in crop rotation, seed saving, and the economic viability of farmers. Farmers and consumers voiced concerns about environmental implications, international market opposition, and the lack of transparency in the formulation of policies and regulation of GM crops (Eaton, 2009, 2011, 2013; Magnan, 2007; Marcoux and Létourneau, 2013). Indeed, as Prudham and Morris (2006, 168) noted "the culturally loaded and embedded character of food as a class of commodities throws these tensions into sharp relief, and biotechnology – as a controversial suite of innovations with intersecting social, ethical, environmental, and health implications – provides rich opportunities for exploring how they work themselves out”.

In this chapter I contribute to the academic literature by providing a different perspective on the role of the state in the development, adoption, and production of GM crops in Canada and internationally. Moving away from institutionalist perspectives that consider the state an autonomous actor and an institutional ensemble that is independent of society, I show that the basic orientations and policies of the state are determined by the pattern of capitalist accumulation, which in turn determine the role and policies of the state towards agricultural biotechnology development. State-led development of agricultural biotechnology in service of the private sector implies a considerable socialization of the relevant costs, which is compatible with the class character of the state. The class character of the state implies that technological development should contribute to the reproduction of the prevailing relations of production. Moreover, and especially under the current conditions of agricultural restructuring, the state tends to follow a technological development policy that contributes to the improvement on the returns to capital. This concerns the agricultural biotechnology industry as well as agriculture and the agro-food system, where the technology may be productively utilized. Growing competition in high-tech industries and the need to improve on the returns to capital are shaping novel developments in agricultural biotechnology in such a way as to allow a flexible restructuring of production and the minimization of the private cost of production.

Other authors have brought into focus a framework for understanding the development of science and technology that emphasizes the interrelationship among agricultural production, biotechnology, and the interventions by the state and civil society organizations. In terms of understanding the role of science and technology in these processes, some authors highlighted the advent of the knowledge economy and the increasing interchange between academic and industrial research, science-based regulation and global trade liberalization, and the relationship between scientists and the public (Kelly et al., 2011; Kinchy et al., 2008). GMO regulatory efforts have been influenced by the scientific community, NGOs, the US and other OECD member countries, international organizations (e.g., Organisation for Economic Cooperation and Development, the National Academy of Sciences, the United Nations Food and Agriculture Organization, and the World Health Organization) and the biotechnology industry. At issue has been the role of governance and the implications of regulation in mediating the debates and managing the associated risks. Various states operating at multiple scales are responding to the opportunities and threats presented by GMOs and the intersection of these dynamics with broader economic, social, and environmental agendas (Freeman et al., 2011; Twardowski and Małyska, 2015; Uchtmann and Nelson, 2000). Although these processes have been anything but linear, often incorporating the shifting positions of industry, the research community, environmental groups, regulators, among others, several authors contend that regulatory measures, often introduced as a response to public and interest group discontent, have generally reduced industrial uncertainty and promoted biotechnology development (Cocklin et al., 2008; Hansen, 2001) by providing billions of dollars in state-provided financial incentives (e.g., tax relief, funding) concentrated among private sector investors and designed to spur innovation (Moretti and Wilson, 2014).

Given these developments, many governments around the world remain committed to a ‘biotechnology future’ that includes novel plants and foods; however, what exactly this future will hold is yet to be determined. Governments that favor the development of biotechnology do so for the advancement of national science and a competitive edge in the knowledge economy, improving competitiveness in food and fiber production, and invoking issues surrounding global food security. Countervailing arguments raise questions about risks to human health and the environment, the lack of democratic decision-making, and the sustainability of farming and rural communities. There can be little doubt, then, that social tensions surrounding GMOs will continue (Cocklin et al., 2008).

Chapter Five

Science, Technology, and Agricultural Biotechnology Discourse

5.1 Introduction

A number of international and national reports have been published that promote the adoption of biotechnology as part of national economic growth and development strategies (see, for example, CGIAR, 2000; FAO, 2004; Government of Canada, 2003; Health Canada, 2005; UNDP, 2001; World Bank, 2007). Apparent throughout these reports is the fostering of science and technology as powerful tools for human progress. People can use technology "to increase their incomes, live longer, be healthier, enjoy a better standard of living, participate more in their communities and lead more creative lives" (UNDP, 2001, 27). The claim is made that scientific research and activities "bring modern science to bear on difficult productivity and institutional problems that have proven intractable in the past" (CGIAR, 2000, 2). Participating in the forefront of scientific and technological development is regarded as an essential aspect for improving human well-being and competing on the global stage (World Bank, 2007). Similar claims are made in the Canadian context. Recent scientific discoveries "have significantly increased our ability to develop new knowledge and innovative products and processes such as pest-resistant crops with higher yields, better disease diagnostic tools, and treatments that complement one's genetic make-up. The life sciences sector is research-based and capital-intensive and could yield positive benefits in such fields as health care, the environment, safety, agriculture, aquaculture, economic development, food safety and sustainable development" (Health Canada, 2005) and "all aspects of the development and application of biotechnology are responsibly managed, striking a balance between the detection and management of risk, and the development of new discoveries, in order to capture the technology's long-term health, environmental and economic benefits" (Government of Canada, 2003, 3).

Embedded in the science and technology narrative is an emphasis on the importance of agricultural R&D and the socio-economic benefits that the adoption of GM crops will bring "when appropriate innovations are developed" (FAO, 2004, 6). This includes capacity building at the technical, institutional, and management levels, the development of appropriate forms of public- and private-sector partnerships in agricultural and social science research and education that focus on development goals, and investment in farmers and other rural actors' learning and capacity to critically assess, define, and engage in locally-directed development processes (FAO, 2004). In the Canadian context, extensive applications of biotechnology have been used to develop plants with enhanced or novel traits. Novel plant traits include herbicide tolerance and pest, insect and virus resistance as introduced into crops like corn, soy, and canola. New applications in food and agriculture promise to provide foods with enhanced nutritional benefits. The results of these initiatives "will contribute to positioning Canada as a world leader in food safety, innovation and environmentally responsible production" (Government of Canada, 2003, 17).

According to Herring (2007, 2), "Science is the fulcrum on which this contentious politics rests. Science as agnostic method for adjudicating truth claims in applied genomics is overwhelmed by a politicised science constructed either as target or legitimation in strategies of corporations, government agencies, evangelical politicians, social movements and NGOs". This debate has produced divergent claims. At one end of the spectrum, proponents argue that there is a contest between science and Luddism. The presumption is made that science answers questions in normative theory and risk preferences. At the other end of the spectrum is the claim that science is transgressing into realms that belong only to God (Charles, 2006), and the depiction of GM crops as 'Frankenfoods' (Serageldin and Persley, 2000). According to this view, the genomics revolution will unleash unimagined evils upon humanity from ecological disasters to bioterrorism. Such "[d]ivergent claims to knowledge reflect and justify widely varying, socially conditioned distributions of risk aversion and risk acceptance" (Herring, 2007, 3).

The purpose of this chapter is to understand how discourses about biotechnology, GM crops, scientific progress, and economic development are employed to sustain and legitimate the use of GM crops. For the purpose of this chapter, discourse refers to a "specific series of representations, practices and performances through which meanings are produced, connected into networks and legitimized" (Gregory, 2000, 180). In particular, "discourses are not free-floating constructions but are materially implicated in the conduct of social life; they are embedded in institutions and subject positions but typically cut across and circulate through multiple institutions and subject positions" (Gregory, 2000, 180). Moreover, discourses may be understood as an inherent aspect of ideology. Following Eagleton (1991, 193-194), ideology is a term that categorizes different things that have to do with signs. For example, 'bourgeois ideology' refers to a wide range of discourses that have a common element, not in the sense of some invariable structure of categories, but a network of overlapping features. Ideology may be regarded as a discursive or semiotic phenomenon where materiality is emphasized and a sense of meanings is preserved. Eagleton stated (1991, 194 italics in original), “Talk of signs and discourses is inherently social and practical…It may help to view ideology less as a particular *set* of discourses, than as a particular set of effects *within* discourses”. Such discourses produce different kinds of effects where certain forms of signification are highlighted and others muted depending on the context of one communication to the next.

Drawing on this conceptualization, I address the following questions: how has the federal government of Canada and industry constructed and sustained a pro-GM crops discourse? In what ways has the pro-GM crops discourse been narrowly conceived? What are the purported benefits of GM crops for adopting countries in the Global North and South? In what ways and how effective has been the dissemination of the pro-GM crops discourse? I argue that the state and sections of civil society, government scientists and bureaucrats, corporations, and industry supported websites and NGOs have played an important role in the construction of a pro-GM crops discourse. Such a discourse sustains and legitimizes the development, adoption, and production of GM crops by positioning agricultural biotechnology as a panacea for perplexing socio-economic problems such as (inter) national economic growth and development, a stagnating agricultural industry, health and environmental issues, population growth and poverty, and so on. The manipulation of the pro-GM crops discourse serves to control the discursive norms and institutional contexts that surround agricultural biotechnology. This process seeks to represent the interest of capitalist accumulation and those of individual capitals as the general interests of the Canadian public and farming communities therefore establishing and maintaining some of the conditions that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

The analysis in the chapter primarily revolves around the fostering of science and technology in constructing a pro-GM crops discourse. I conducted interviews with five Government of Canada scientists, three anti-GMO activists from Greenpeace Canada and the CBAN, two farmers from the Canadian NFU, and two government bureaucrats from Industry Canada. A number of general questions were asked about attitudes toward biotechnology, how GM crops issues are best communicated to the public, the links between the government and industry, and other broader topics including the future of plant biotechnology and reasons for the negative public reactions to GM crops in Canada and different places around the world. Select responses were gathered from the interviews that demonstrate the various ways a pro-GM crops discourse has been constructed. In addition, I identified common words, phrases, and ideas which are routinely employed by government and industry in publications and websites which purport the great benefits that technological advancements in agricultural biotechnology and the development, adoption, and production of GM crops will reap for the Canadian public and farming communities. Lastly, I scrutinize various public meeting reports, pro-GMO websites, and media publications through which the pro-GM crops discourse has been disseminated.

The chapter is organized in the following way. In section **5.2 Constructing a Pro-GM Crops Discourse** I examine the ways ‘sound science’, the ‘authority’ of scientists (section ***5.2.1 ‘Sound Science’ and the ‘Authority’ of Scientists***), and the appeal to science (section ***5.2.2 An Appeal to Science***) are employed to sustain and legitimate the adoption and production of GM crops. In section **5.3 Disseminating the Pro-GM Crops Discourse** I scrutinize the various methods through which the pro-GM crops discourse is disseminated. In section **5.4 Conclusion** I provide a summary of the findings, draw out some conceptual implications, and situate the contribution of the chapter in the broader academic literature.

5.2 Constructing a Pro-GM Crops Discourse

5.2.1 'Sound Science' and the 'Authority' of Scientists

One of the ways that the Government of Canada and the Canadian industry have sustained and legitimized the adoption and production of GM crops is by constructing a pro-GM crops 'science-based' discourse. This has occurred in part by drawing on and propagating opinions from 'authoritative' sources in the debate over the use of GM crops. The Government of Canada scientists and bureaucrats have played an important role in this regard. Comments from interviews with government scientists and bureaucrats illustrate how ideas about 'proper' science conceived by a narrowly defined scientific community, and an ill-informed, naive, and irrational public, that lacks an understanding of the notion of absolute versus relative risk, have been used to construct this discourse.

A clear distinction was made by government scientists that I interviewed between what they considered 'expert' and 'non-expert' opinion in the debate over the use of GM crops. The former was often associated with a narrowly defined scientific community and the latter with those outside of that community. The general assumption was that only opinions from ‘proper’ scientists were valid while opinions from people with some scientific training, social scientists, or scientists that are opposed to GM crops, are for the most part simply dismissed. This may be illustrated by the following response from a government scientist when discussing the development of agricultural biotechnology.

> At the risk of sounding derogatory, there are very few scientists that really understand the technology. I mean, let’s face it, for those scientists that reject the technology, the question I have is on what scientific basis are they doing this? Most of the criticisms we hear are based on opinion and not on scientific facts. The scientific community that supports this technology has based its opinion on scientific findings derived from proper scientific enquiry, and quite frankly, there are relatively few people in that community that do not support the development of this technology and for those that do not agree, well then I would question on what basis they are reaching their conclusion. I would say that, as far as I am concerned, scientists who do not understand the technology should be more rational in their approach and listen to those who do because they are getting themselves worried about areas that they know very little about (Government of Canada Scientist 1).

This perspective problematically makes the assumption that there is consensus among scientists regarding the development of agricultural biotechnology, when in fact the scientific debate has intensified both inside the Government of Canada’s scientific community and outside of it. For example, 200 scientists from Health Canada's Health Protection Branch signed a petition that, among other things, raised alarm at the acute shortage of scientists for evaluation and risk assessment of GM foods. Public-health critics also attacked the regulatory system for relying on data supplied by industry rather than original research (Tam, 1999). In addition, many studies by world-renowned scientists that highlight some of the negative impacts of GM foods have been published in peer-reviewed scientific journals despite the claim that such studies are flawed. One of the most publicized cases that demonstrated the maligning of independent research was that of world-renowned expert on lectins Pusztai, whose research indicated that a GM potato diet weakened rats' immune systems and adversely affected the animals' internal organs. Pusztai shared with the media his findings, following which he was sacked from his research post with Scotland's Rowett Research Institute, his research team was disbanded, his research papers were confiscated, and he was prohibited from speaking with the media (Verzola, 1999).

An activist from Greenpeace Canada in an interview commented about the narrow aspect of the 'science-based' discourse that the Government of Canada scientists and corporations have generated. The issue that was raised concerns the relationship between agricultural biotechnology research funding, which has predominantly come from the biotechnology industry, and the dissemination of information about research findings. This raises concerns about the data generated from the biotechnology industry about GM products. In addition, public awareness about which foods are made with genetic modification has been curtailed due to a lack of transparency from the biotechnology industry.

> Part of the strategy for corporations and the government has been to delegitimize the public's opposition to a particular technology by narrowing the debate to very specific issues, like the importance of 'scientific' research, at the expense of socio-economic factors that go beyond the science-based discourse. This is made possible, in part, because of the mass budgets and resources available from the corporations and the government to disseminate their own positions on biotechnology and genetic engineering. Also, for the most part, the public is not even aware of how pervasive the use of genetic engineering has become. We are all consumers of genetically engineered products, whether or not we are aware of it. So, the silencing part of the discourse has been just as effective. It is not only about what they tell you, it is also about what they do not tell you. For this reason, among others, lay knowledge has been very limited (Greenpeace Canada Activist 3).

Additional interviews with government scientists demonstrate the undermining of public disquiet as ill-informed, naive, irrational, and lacking an understanding of the notion of absolute risk versus relative risk.

> Sometimes I think there is no point in discussing these things with the public or even researchers because I feel like I am talking to people that really do not understand enough of the technical aspects of the technology. There's no point just discussing GM because that's in a vacuum. To discuss GM you have to have people knowing what's happening in genetics, what's happening in biology, what's happening with the food position, what does nutrition mean, and on and on. Now, I am not saying that I am well versed in all these areas and can say something worthwhile about every aspect of this technology, no, but I am a geneticist and have had extensive training and experience in this particular area and can speak intelligently about certain issues regarding GM, however, this is a conversation that I can only have with other scientists and not the general public (Government of Canada Scientist 2).

People outside of this scientific community were predominantly conceived as having no relevant expertise, any intermediate degree of scientific knowledge, or any general critical ability in assessing the arguments of 'experts' and 'pressure' groups. This perception is then used to explain the vulnerability of those outside this scientific community to manipulation by opponents of GM crops, including anti-GMO groups, and consequently as something to be remedied by education. Any concerns about the risks associated with GM crops and reassurances of risk-free GM crops were often viewed as the result of a lack of understanding of the notion of absolute versus relative risk. These points may be illustrated by the following quotes from interviews with two government scientists.

> The rise in many of the anti-GMO groups, websites, farmers, and the rest of it, in my opinion, is because of the incredible amount of misinformation out there in the public. It is relatively easy to sway people against GM

> because there is a lack of education and understanding about the technology. A lot of this has been driven by green parties, which I think play on the fears of the unknown. A lot of the rather sensationalist press has got a lot to do with the very anti-feelings about GM in this country at the moment, because scare stories sell papers, and good news doesn't. Once people become better informed than I think we will see a turn in terms of the support for the technology (Government of Canada Scientist 3).

> The public in general is concerned about the risks involved with the adoption of GM crops. This to me seems like one of the biggest issues. For this reason many people are absolutely against the adoption of GM crops. Those that are against it because of the risks involved usually have a naive conception of risk. They want to be told that there is absolutely no risk, and as a scientist I can't tell them that. I can't say to the public that it is absolutely safe, and for the public to expect that any kind of technology has no risks attached to it is completely irrational. All you can do is tell people that up to this point the technology has been reasonably safe. Of course, mistakes have been made, and accidents have happened, but when you say this, then the response is, 'aha, you mean it's not safe' and my response is, 'no, I didn't say that, I said it has been reasonably safe'. This kind of reaction is generally the result of a lack of education about, one, the issues with the development of any technology, and two, an understanding of what risk entails (Government of Canada Scientist 4).

The claim that the public lacks knowledge and can only engage on an emotional level with the issues was then key to a further argumentative twist, allowing public opposition to be explained as entirely created by the media and NGOs, rather than the possibility that such opposition was spontaneous, considered, or an autonomous response. This characterization of public opinion appeared to free the government scientists that I interviewed from having to engage with public disquiet. When asked directly, many of them spoke in favour of communicating with non-experts, although what seemed to be envisaged was a one-way communication in which members of the public would be educated. The impression was as if there are no members of the public or scientists who are also campaigning proponents. Opposition to GM crops was seen as emanating from organizations acting upon a malleable and passive public, rather than from the public itself. The two main sources of opposition were seen as campaigning NGOs and the media, all of whom were judged to be acting in their own interests and making decisions without authority on the public's behalf. Journalists were seen as fickle, unconcerned with truth, and motivated only by the need for a 'good story'. Anti-GMO protestors and activists were less frequently mentioned, though when they were, it was often in a condemnatory manner.

The sentiment of scientists has also been supported by government bureaucrats who do not permit including 'non-scientific' issues into regulatory assessments of GM crops. The Conference Board of Canada (2016), for example, is an "independent, evidence-based, not-for-profit applied research organization in Canada" that has been supportive of the biotechnology industry by opposing any efforts to introduce non-scientific issues into regulatory reviews because of concerns over lengthening the review process and approval time-frames (see Munn-Venn and Mitchell, 2005). This perspective was also voiced in an interview with an Industry Canada employee.

> What makes the whole thing so complicated is that the public does not know or understand the benefits from all the biotechnology applications. We take comfort that the decisions we make are made in conjunction with technical experts, who really know what they are talking about. The anti-GM people just hate the technology and for a lot of different reasons. Depending on who you speak to – some only want organic, others are just scared, and others have made it their life mission to just be anti-GMO. Well, how in the world do you take everyone's ideas into consideration? People who are opposed want us to interweave political, societal, ethical, emotional issues and if you do that you will just delay everything, increase costs, have unnecessary testing and labeling, all these issues are really non-science based. You just can't respond to everything everyone has to say about GM. Do these people really have any idea how beneficial this

> technology has been for Canadians? Look at the canola industry, this is one of Canada's success stories (Industry Canada Employee 1).

By disregarding public concerns about biotechnology, the Government of Canada has maintained the perspective that the public, for the most part, is ignorant of the purported benefits that the technology will reap for Canadians. One farmer from the NFU in an interview stated, "By suggesting that the new 'religion' is science and its high priest is the 'scientist' the Government of Canada and industry have been successful at promoting that the 'truth' about biotechnology should be almost blindly accepted" (NFU Farmer 1). This has been an effective strategy, on the one hand, the Government of Canada has been actively promoting and supporting the development of the biotechnology sector for more than twenty-five years, and on the other hand, the multinational corporations that dominate that sector have been aggressively marketing the technology. Any attempts at questioning these processes and in any way hindering their development is met with obdurate resistance on the part of government scientists, bureaucrats, and the industry.

In an interview with another NFU farmer, similar sentiments were expressed. The issue raised here is the relationship between regulatory approvals and the kind of information released about agricultural biotechnology. While a 'science-based' approach to biotechnology regulation on the surface appears to be neutral, it becomes clear following some scrutiny that the primary objective of such an approach is the support and promotion of the industry, while all along the Canadian public and Canadian farmers have been told that this is in their best interest.

> The government and the industry have worked really closely together in constructing the regulatory process. By doing this, what they have

> essentially done is control the kind of information that they generate about GM. This way only the type of information they want to be included in the regulatory reviews actually gets included and the information they do not want is simply left out. We hear a lot about the science and we hear a lot about how this is going to help the farming industry and farmers but I am very wary about it all because it seems to me that it's more about the GM people who are benefiting the most from all this, especially the big corporations selling us all the products, and somehow this is great for all Canadians and for farming? I don't really trust everything they say and I really wonder how much of it is true and how much is a big smoke screen for a bunch of executives and bureaucrats to make more money from the farming industry while telling all the public that this is going to help everyone and somehow GM is the answer to all the farming issues (NFU Farmer 2).

In summary, the Government of Canada and the Canadian industry have constructed a pro-GM crops 'science-based' discourse. The Government of Canada has distinguished between, on the one hand, 'proper' science and 'expert' opinion conceived by a narrowly defined scientific community, and on the other hand, the 'flawed' studies and 'non-expert' opinion of those outside of that community. This has occurred despite the fact that there has not been a clear concensus among government scientists in Canada and internationally as to the effectiveness of the scientific evaluation and risk assessment of GM crops, where in some cases studies that highlight the negative impacts of GM crops have been maligned.

Also, some government scientists have undermined public disquiet as ill-informed, naive, and irrational. The public has been predominantly viewed as having no relevant expertise, any intermediate degree of scientific knowledge, or any general critical ability in assessing the arguments of 'experts' and 'pressure' groups. As a result, the claim has been made that the public is malleable, often succumbing to manipulation by anti-GMO groups. Any concerns about the risks associated with GM crops were often viewed as the result of a lack of understanding of the notion of absolute versus relative risk.

Lastly, the sentiment of government scientists has also been supported by government bureaucrats who do not permit including ‘non-scientific’ issues into regulatory assessments of GM crops. Although incorporating a more rigorous regulatory practices may appease a generally distraught public, the claim is made that such practices would unnecessarily lengthen review processes and approval-times, and therefore deny the purported benefits that GM crops will bring to the Canadian public and farming communities.

5.2.2 An Appeal to Science

Given the authoritative role of scientists, perhaps the most deeply rooted premise in the pro-GM crops discourse is that the answers to all questions about the use of GM crops are to be found exclusively in the confines of science. It is as though, once the scientific evidence can be agreed upon, then all the purported benefits from the development, adoption, and production of GM crops will automatically follow. This problematically implies that there are only two criteria surrounding the debate about the use of GM crops, ‘scientific’ and ‘non-scientific’, and thus denies the validity of any other criteria (e.g., political, economic, cultural). To say that there are dimensions of the debate which are not scientific, however, is neither to dismiss scientific evidence nor to succumb to irrationality and prejudice. Although scientific findings are of critical importance, they do not encompass the entire debate over the use of GM crops. The concern, in other words, has been much more with an appeal to science rather than with science itself. This reflects a common supposition that when a scientist speaks, in whatever forum, on whatever topic, and in whatever style, something of his or her authority carries over into other domains. In this way, science has come to be seen less as a way of proceeding or as a mode of thought, and more as the property of a particular group of people (Cook, 2005, 77-80). Government scientists that I interviewed subscribed either implicitly or explicitly to a causal relationship between scientific evidence and action regarding the use of GM crops with little to no consideration of any other issues.

> Those of us in the labs and with the right kind of training are the ones who are doing all the research. That's why we insist that this is proper scientific work, and that's why we are convinced that the results we have are the right results. We are engaged here in very serious business with very highly trained people. When regulatory decisions are made it is because those decisions are made based on sound scientific facts. Obviously, the people that are against what we are doing do not understand the science, and maybe they have their own agendas. I can't really speak for them, all I can tell you is the Canadian public has nothing to worry about. The bottom line though is that our experiments, and believe me millions and millions has been spent on this, at the end of the day show that there is nothing that we need to be worried about. We, as scientists, are committed to the development of this technology. This is not something which we do independently; we work as part of a group under strict science-based regulations. A lot of this is carried out in partnership with other federal government organizations, as well as industry people, university academics, and even people from NGOs (Government of Canada Scientist 5).

> We have to put our trust in scientific facts and not what people's opinions are about this or that technology. Also, I think that the Government of Canada is relying on scientific-based evidence to make decisions about whether or not to continue with the development of biotechnology in agriculture or any other field. Once we know the facts then we can make the right decisions. It is really just as simple as that (Government of Canada Scientist 3).

The appeal to science may also be illustrated by some of the common words, phrases, and ideas which are routinely employed by government and industry that sustain and legitimize the pro-GM crops discourse and the use of GM crops. The following are some examples of the various claims made by Government of Canada websites and reports. Scientists, technicians, and staff work "to create better opportunities for farmers and all Canadians through agricultural research and innovation" (AAFC, 2016). Agricultural biotechnology research activities are aimed at "the development of new food products through a variety of scientific tools and techniques" (Health Canada, 2014). Canadian producers and processors "are free to adopt technologies that have undergone science-based safety assessments under Canada's rigorous regulatory system. Some Canadian producers have determined that new technologies, including GM crops, provide important benefits, and have adopted them" (Government of Canada, 2014). Canada's participation in "international knowledge networks on biotechnology and sustainable development…improve the quality of life of people in developing countries" (Government of Canada, 2007, 7). AAFC "works to improve Canadians' quality of life by undertaking research and development programs that support the production of safe and nutritious food, maintain a healthy environment and develop innovative technologies. Biotechnology is an important tool in helping AAFC's scientists secure this goal" (Government of Canada, 2003, 16).

Similar claims are made by industry-supported and corporate websites. According to BIOTECanada (2009), "With increased knowledge of plants through genome sequencing projects we will see continued improvements in yield and quality of food crops…In the future, consumers will be able to choose fruits and vegetables that stay fresh longer and grains that contain essential micronutrients or healthier oils". According to the International Service for the Acquisition of Agri-biotech Applications "biotech crops can be used collectively for 'speeding the breeding'…range of traits include those for improved drought and salinity tolerance, yield enhancement, efficient nitrogen utilization, increased nutrition and food quality, resistance to pests and diseases, including resistance to viruses" (James, 2013). Monsanto (2014b) pledges to "share knowledge and technology to advance scientific understanding, to improve agriculture and the environment, to improve crops, and to help farmers in developing countries". DuPont (2016) claims to be "the premier specialty food ingredient and safety leader [bringing] together a wide range of sustainable food ingredients to increase the quality of food products, while improving their health profile and shelf life". Syngenta (2016) claims to be a "business that helps humanity face its toughest challenge: how to feed a rising population, sustainably. Our world class science and innovative crop solutions transform how crops are grown to enable millions of growers to make better use of available resources". In general, the message behind these statements is that technological advancements in agricultural biotechnology and the development, adoption, and production of GM crops will reap great benefits for humanity. Such statements, however, prejudge the issues which are supposed to be under discussion: whether or not the use of GM crops will result in all the purported benefits. Also, there is a virtual absence of reference to the political and economic implications of the use of GM crops (e.g., how policy decisions are made about it, the nature and speed of its implementation, or accusations of improper influence being exerted by governments, corporations, or scientific bodies) even though some of these issues feature prominently in the anti-GMO literature and in reactions of the public to GM crops.

In addition, there is a blurring of the distinction between genetic modification and natural processes, where the former is normalized as part of the latter, further legitimatizing the development of biotechnology as part of the history of the genetic manipulation of plants (Stone, 2010). For example, the Canadian National Research Council's Institute for Nutritional Biosciences and Health maintained that its R&D focus is "on developing bioactive compounds from natural products" (Government of Canada, 2003, 67) and that the Canadian Institute for National Research Council Plant Biotechnology research programs are regarded as part of the development of high-quality crops that enhance "naturally derived plant compounds" (Government of Canada, 2003, 70). Moreover, according to the Canadian Biotechnology Advisory Committee, the boundaries between genetic modification and natural processes are expected to be pushed even further "challenging old categories around which we have constructed our worldview and our institutions – "agriculture vs. medicine", "natural vs. artificial", "animal vs. human", "machine vs. living being", "person vs. object", etc." (CBAC, 2006, 4). Similar claims were made in some of the international literature. According to an OECD (2009) document, biotechnology has become so pervasive in global crop improvement programs that it is no longer useful to delimit categories such as 'conventional' and 'modern' when discussing crop breeding. Also, according to a FAO (2011, 6) document, the "sharp category distinction between non-transgenic and transgenic approaches might be somewhat contrived in breeding terms, and may not be recognized by all crop scientists".

This framing uncritically sustains “The “plant manipulation as progress” narrative”, where “domestication is genetic modification”, and is often combined with “the Malthusian specter of famine…casting hunger as a condition of nature” (Stone, 2010, 384). This may be illustrated by various statements on corporate websites: “[w]ith global population expected to grow by 40 percent in the next few decades, agriculture will need to become more productive and more sustainable in order to keep pace with rapidly increasing demands. Many experts agree we will need to grow as much food in the next 50 years as we did in the past 10,000 years combined if we are to sustain our planet” (Monsanto, 2014c); and “More than 2.5 billion people depend on agriculture for their livelihoods. Improving the income of these people would be a great leap towards advancing the UN Millennium Development Goal of eradicating hunger and poverty. As a company, we can help the farming community to prosper by providing tools that make agriculture more productive, efficient and profitable” (Syngenta, 2013a, 15). According to former DuPont Chair and Chief Executive Officer Ellen Kullman, “DuPont has a unique vantage point on food security because we have innovations across the full value chain, allowing us to holistically address the challenge of feeding the growing global population. Improving agricultural productivity, providing food and nutrition solutions and finding ways to protect food and reduce waste are all part of our strategy” (DuPont, 2014b). Industry-supported websites make similar claims: “[a] growing population signals a global challenge requiring we grow food more efficiently and with greater nutritional value…A strong agricultural sector coupled with biotech innovation will position Canada and Canadian farmers to take advantage of the global opportunity…Feeding the world's growing population, projected to surpass 9 billion by

2050, requires farmers to produce 70% more food on less land than ever before" (BIOTECanada, 2016); and "[f]ood, feed, fiber, and fuel for the world's 800 million people who suffer from hunger and poverty – this is the formidable task for many countries, development agencies, and other interest groups. Of the many strategies that have been forwarded to address the issues of global poverty and environmental degradation, crop biotechnology is seen as a viable contribution to the solution" (ISAAA, 2015). This sentiment is also acknowledged by the Government of Canada. According to the Chair of the Report of the Standing Committee on Agriculture and Agri-Food Larry Miller (2012, 48), biotechnology in farm production "is needed in order to increase farm productivity around the world and meet such challenges as a growing population, the need for water and climate change"; and "Canada's food producers will increasingly depend on biotechnology. With most of its potentially arable land already in production, Canada's capacity to meet the ever-expanding demand for more and better food products by a growing world population will depend on such innovations" (Government of Canada, 2003, 17).

Much of the rhetoric about the benefits of GM crops for growing populations and feeding the poor is predicated on a form of neo-Malthusianism, which is a combination of Malthusianism and technological determinism (see Das, 2002, 60-65 for a related discussion on the Green Revolution technology). Some authors claim that GM crops technology is beneficial for the poor because of the physical properties of the technology: the technology will benefit small-scale resource-poor farmers because it is scale neutral (Lele, 2003); insect resistant GM crops alleviate financial vulnerabilities of farmers because the plants' own biological processes substitute for cash-intensive inputs such as insecticides (James, 2014); the poor will gain significant opportunities to improve their lives because GM crop technology addresses issues such as population growth, scarce land resources, environmental degradation, and climactic change (UNDP, 2001). Moreover, they claim that the technology can be and ought to be more beneficial for the poor: GM crops developed and released for production ought to target the key food crops (rice, wheat, cassava, plantain, millet, sorghum, and legumes) and traits (resistance to drought, insects, diseases, and low yield and soil fertility) required by small-scale resource-poor farmers in developing countries (Fukuda-Parr, 2007). These points suggest that there is a necessary relationship between GM crop technology and poverty reduction; however, the effect of the technology on poverty reduction is contingent. The only necessary effects of GM crop technology are technical or physical (e.g., greater yield), but the social effects (e.g., poverty reduction) are contingent. To make the claim that GM crop technology is beneficial for the poor is to grant technology much more power than it can possibly have.

Underlying the technological determinism is the looming threat of population growth. Borlaug, the Nobel Peace Prize laureate in 1970 for the Green Revolution technology claimed, “Feeding 10 billion people” is “our twenty-first century challenge” (quoted in FAO, 2004, 26). International authorities on food and hunger and the winners of the World Food Prize in 2001 Pinstrup-Andersen and Schiøler (2000) argued that food production must increase at a rate faster than population growth. Leading scientist on biotechnology and the winner of the 2007 National Medal of Science Federoff noted, “molecular modification is the safest and most powerful technology we’ve ever developed for the daunting task of continuing to increase the amount of food for a growing population and doing it more sustainably" (quoted in Navarro, 2015, 3). The main point these authors were making was that a growing population can be fed from constant land only through the application of GM crop technology; however, a population's relation to poverty directly or its relation to GM crop technology's impacts on poverty is also contingent. Indeed the application of GM crop technology may increase food production, but whether or not this will result in reducing hunger in developing countries depends on a number of other factors. What is underemphasized are the multiple determinations of population growth and poverty such as unequal power structures at multiple scales that affect the way food and other goods and services are produced and distributed, pauperization and proletarianization, income levels, social provisions, and so on. As Altieri and Rosset (1999) argued, both densely populated countries such as Bangladesh and Haiti and sparsely populated countries such as Brazil and Indonesia go hungry despite the fact that the growth of the global agricultural productive potential has been more than sufficient to exceed population growth. Also, global per capita food availability has risen from approximately 2220 kcal/person/day in the early 1960s to 2790 kcal/person/day in 2006-08, while developing countries recorded a leap from 1850 kcal/person/day to over 2640 kcal/person/day (FAO, 2012). Most innovations in agricultural biotechnology, however, have been profit-driven rather than need-driven. The real thrust of the agricultural biotechnology industry is not to make agriculture in developing countries more productive so as to address population growth and poverty, but rather to generate profits.

Such statements and ideas have been given further legitimacy by asserting they are based on 'sound science'. This phrase routinely appeared in corporate and government websites and documents: Monsanto advocates "for supportive policies, regulations and laws based on principles of sound science" (Monsanto, 2015b). Syngenta's best management practices "were developed through sound science, common sense, and public outreach" (Syngenta, 2013b). Bayer's product stewardship principles include developing "quality varieties which will offer greater choice and improvements in crop production. Through sound scientific techniques new seed technologies will further advance this offering providing useful and improved seed products to customers" (Bayer CropScience, 2009, 7). The CFIA asserts that the "key to reliable regulation for consumer protection is sound science. The CFIA has undertaken numerous research initiatives to enhance its detection and identification capacity for various biotechnology-derived products, including plants with novel traits (PNTs) and novel livestock feeds" (Government of Canada, 2003, 22). Health Canada (2006) stated, "The increasing complexity and pace of advancement of new knowledge, together with the increasing impact of scientific and technological change on our lives, have intensified the demand for sound science advice in governance. But science is not the sole domain of governments. Sound science advice rests on a foundation of excellent science that has been widely sought and subjected to rigorous evaluation of its quality". These issues are addressed through a variety of different programs and activities that promote awareness about 'sound science' and research including the Health Canada Science Forums and the Omyot Lectures. The annual Health Canada Science Forum was inaugurated in 2002 in order to give researchers and scientists the opportunity to present and discuss their work and showcase major achievements. One of the event's goals is to encourage a better understanding of Health Canada's scientific programs and activities. The Omyot Lectures are a series of presentations given by distinguished Canadians in the health field to recognize excellence and to foster innovation and debate on leading health policy issues.

The phrase ‘sound science’ implies that there is another type of science that is ‘unsound’. Science may be unsound in the sense that, while genuinely trying to follow scientific principles, it is full of mistakes: the methods are flawed, the evidence is wrong, or the calculations and inductions are incorrect. This is the kind of allegation which is often levelled by proponents of GM crops against the work of those scientists who are opponents of GM crops. Cook (2005, 95) noted, “The phrase ‘sound science’ is not in itself very sound. When used by scientists it can become self-congratulatory (rather like Monsanto’s ‘thoughtful dialogue’) and circular: an epithet awarded by those on one side of a scientific dispute to themselves, and denied to their opponents”.

In summary, the appeal to science rather than science itself may be illustrated by common words, phrases, and ideas which are routinely employed by government and industry in publications and websites. In general, the message behind these statements is that technological advancements in agricultural biotechnology and the development, adoption, and production of GM crops will reap great benefits for humanity, including addressing perplexing problems such as (inter) national economic growth and development, a stagnating agricultural industry, health and environmental issues, population growth and poverty, and so on. Also, there is a blurring of the distinction between genetic modification and natural processes, where the former is normalized as part of the latter, therefore legitimatizing the development of biotechnology as part of the history of the genetic manipulation of plants. This framing is often combined with a form of neo-Malthusianism where the suggestion is made that there is a necessary relationship between GM crop technology and poverty reduction and that a growing population can be fed from constant land only through the application of GM crop technology. Lastly, these ideas are given further legitimacy by the assertion that they are based on 'sound science'. This phrase routinely appeared in corporate and government websites and documents and implies that there is another type of science that is 'unsound'. Science may be unsound in the sense that it is full of errors: the methods are flawed, the evidence is wrong, or the calculations and inductions are incorrect. This is the type of allegation which is often levelled by proponents of GM crops against the work of those scientists who are opponents of GM crops.

5.3 Disseminating the Pro-GM Crops Discourse

The Government of Canada has been actively engaged in the promotion of agricultural biotechnology since the late 1990s using various methods. This, in part, was due to the increase of consumer and activist groups that were apprehensive about the number of genetically engineered food products that began appearing in the market. Also, in the European context, Greenpeace along with Friends of the Earth played an instrumental role in challenging the European Union's relatively permissive and supportive biotechnology strategy resulting in significant policy changes between 1996 and 1999 which ended with the European Union turning against the adoption of GM products (Tiberghien, 2007). Accordingly, then federal minister for the AAFC Lyle Vanclief held a meeting that included: government bureaucrats; industry insiders (Byron Beeler, then president of Novartis and Ray Mowling, then president of Monsanto); industry lobbyists (Joyce Groote, then communication expert with BIOTECanada and Diane Weatherall then communication expert with the Food Biotechnology Communications Network); and media personnel (Anna Hobbs, then associate editor of *Canadian Living* magazine). The purpose of the meeting was for government and industry to partner together along with other third party members in order to sway public opinion in favour of the development of agricultural biotechnology (Peekhaus, 2013, 202). An activist from the CBAN explained,

> I think what was happening in Europe was key. You have to keep in mind that at first Europeans really embraced the idea of introducing GMOs into the food supply. What was happening there was similar to what was happening in the US, if you can believe that, everyone was on board; scientists, the public, the industry, farmers, you name it, there was even approval of products for import as well as production inside some countries, but things really started to change after the mid-90s. It was actually our organization that was active raising awareness about the reality of GM foods. We were also joined by other NGOs, green parties, and even anti-globalization groups. You know, this wasn't easy, it was a struggle and there was a lot of divisions at first even inside many European governments, but eventually some very restrictive policies were implemented in different countries and by the end of the 90s there were severe limits on the production and implementation of GM products. Now, with all of this taking place, you can bet that other governments, including Canada, as well as the major industry players were watching and wondering if the same thing can happen elsewhere. I mean, really, the entire industry was at stake if what happened in Europe spread. There was a concerted effort that was made to promote GMOs in Canada beginning in the late-90s. This was a proactive move on the part of government and industry, because there was resistance in Europe and already people were starting to question GMOs in Canada. Millions and millions had already been spent developing products, both inside the government and industry. Canada is a major producer of canola, and policy makers saw Canada as having strategic national interest for expanding and maintaining export competiveness, with farmers hopefully benefitting financially. Of course, all of this supposedly depended on adopting GM varieties, which brings in the interests of huge corporations,

> like Monsanto, that were aggressively marketing and selling their products not only in Canada but a lot of other countries. It was a kind of case where big business and government came together for their own benefits with little concern about what the hell the rest of us thought (CBAN Activist 3).

The promotion of agricultural biotechnology has not been a small affair. Between 1997 and 2003, more than $13 million dollars was spent by the Government of Canada on various communications. For example, the CFIA spent $2.5 million producing and distributing to all Canadian households a pamphlet entitled *Food Safety and You*. This document focused on ensuring the public about Canada's high standards of food safety and regulation. $1.3 million went to the Consumers' Association of Canada. Founded in 1947, the association is Canada's longest serving and most respected consumer organization whose mandate is "to inform and educate consumers on marketplace issues, to advocate for consumers with government and industry, and to work with government and industry to solve marketplace problems" (Consumers' Association of Canada, 2016). The Consumers' Association of Canada and the Food Biotechnology Communications Network (FCBN) spent $300,000 producing a supplement for the *Canadian Living* magazine entitled *A Growing Appetite for Information: Food Biotechnology in Canada*. The supplement stated, among other things, that the intent of its publication was to provide a "bias-free zone ... [and] a basic introduction to food biotechnology in Canada. We look at products already on the market and those being developed, how products are approved in Canada, a dash of science, and a listing of Canadian government ministries, organizations, and associations interested in food biotechnology" (see CBAN, 2016a). The target audience was women, the primary readers of the magazine and the main decision-makers regarding food purchases in

Canadian households. \$750,000 went to the FBCN. Although disbanded in 2002, the FBCN provided science-based facts about agricultural biotechnology that targeted different stakeholders including farmers and consumers. Dissemination of information included information kits, resource sheets on a variety of topics, a referral network of experts (150 corporate members from the biotechnology and pharmaceutical industry), and a toll free information line. \$5.7 million went to the national industry association BIOTECanada. This association represents Canada's health, industrial, and agricultural biotechnology sectors. The Industrial & Agricultural Committee is focused on the development of policy, advocacy, and investment that enable the biotechnology industry to penetrate traditional agricultural and industrial domestic and global markets with biotechnology products and seek solutions to environmental challenges. BIOTECanada has been directly involved in eliminating 'zero-tolerance' policies to ensure the continued adoption of agricultural biotechnology globally and to continue to have products of agricultural biotechnology bring value to the marketplace (Peekhaus, 2013). In general, the primary purpose of these efforts were threefold: first, the Canadian government wanted to ensure the public of its high standards in food safety and stringent food regulatory system. Second, there was an effort to bring government and industry together under the common banner of promoting agricultural biotechnology, raising public awareness, and reducing public concerns. Third, the underlying premise behind much of the campaign was a 'balanced', 'science-based', 'bias-free', and 'credible' approach to agricultural biotechnology that includes major stakeholders from scientists, to farmers, to consumers. An activist from Greenpeace Canada explained.

> I just like to think of the whole thing as a great marketing campaign which the Canadian public fitted the bill for. A lot of it is propaganda; there is no

> effort made to show any kind of perspectives that go against that of geneticists and the biotechnology industry. The government and the industry are going to shove this stuff down our throats no matter what. I remember listening to a CBC radio program way back when there was a lot of controversy over the fact that the Canadian Food Inspection Agency refused to publish anything negative about GMOs. There were even scientists, like David Suzuki for example as well as plenty of people in the US, who were genuinely concerned, but somehow their opinions never made it into any official documents. Any critical assessments always seem to be pushed under the carpet and receive little to no coverage in the media. When you read anything that has been written on any pro-biotech government website or some of the published documents you begin to realize that it is the same message everywhere. They basically promote all of their perspectives on every issue from labelling to regulation. You can't underestimate this kind of manipulation and misrepresentation to convince the Canadian public that somehow, all of a sudden, life can't continue without GMOs and that somehow their introduction is going to make us all better off. When do we hear about alternatives? Well, never; what we do hear about over and over is the reproduction of all the assertions and assumptions made by scientists and supposed experts that portray new technologies in a positive manner (Greenpeace Canada Activist 4).

When discussing the issue of promoting agricultural biotechnology in an interview, an Industry Canada employee stated,

> Look, the Government of Canada is obviously committed to the economic development of different industries including biotechnology, not just in agriculture, but other areas as well. This is a big part of building the Canadian economy. Of course we work with industry people, scientists, academics, media; in particular, the biotech industry, especially in agriculture, has taken a real hit. There are a lot of opinions out there about GMOs and quite frankly most of these are not accurate. This sort of thing has an impact on the industry, I mean, in Canada we have not had as much opposition as they have had in Europe, for example, but nevertheless it has not exactly been smooth sailing either, especially when you take into consideration how opposed some people were, and still are, to introducing RR wheat. This sort of thing is not good for anyone, not for Canadians, not for the industry, and certainly not for farmers. Take a look at the success of the canola industry where there has been a great deal of acceptance of biotechnology products. So we have to do whatever we can to inform the public, and having a lot of NGOs that hate GMOs makes it much more difficult. We work with some of the best scientists in the world and we take what they say very

> seriously. It's not by accident that Canada is second only to the US in the number of biotechnology companies in this country, this has happened because we support these industries, and this is not something we do with blindfolds; this is based on hard evidence from highly trained scientists, academics, economists about what the future of this industry can mean for Canadians in terms of making an impact with this technology both economically and being world leaders in one of the most important areas of scientific development (Industry Canada Employee 2).

In summary, given the increasing tensions surrounding the development, adoption, and production of GM crops both in the Canadian context and globally, a concerted effort has been made by the government and industry at swaying public opinion in favour of the development of agricultural biotechnology using public meetings, publications, pro-GMO websites, and the media. This has been accomplished under the guise of ensuring the public of the Government of Canada's commitment to high standards in food safety and regulation and a 'science-based' approach to agricultural biotechnology that includes major stakeholders from scientists, to farmers, to consumers.

5.4 Conclusion

The pro-GM crops discourse serves to, at best assuage and at worst sever, any meaningful debates and active participation of the public in determining the outcomes of the development of agricultural biotechnology. In particular, government and industry have been successful in narrowing the debate so that social, political, environmental, and ethical concerns (i.e., so-called 'non-scientific' concerns) have been to a great degree elided. This has been accomplished by constructing a discourse that, on the one hand, disarms any opposition to the development of agricultural biotechnology, and on the other hand, ensures the economic viability of the industry. By manipulating the pro-GM crops discourse, government and industry are actively engaging in strategies designed to control the discursive norms and institutional contexts that encompass agricultural biotechnology. This obscures the interest of capitalist accumulation more generally and those of individual capitals more specifically as the general interests of the Canadian public and farming communities and in part establishes and maintains the conditions conducive to capitalist accumulation. Since class struggle is inherent to capitalist relations of production, capital is compelled to engage in different strategies that provide the basis for accumulation in order to safeguard its existence. Any threat to the balance of power between classes that impedes capitalist accumulation is susceptible to such strategies (Peekhaus, 2013). This may be illustrated, as discussed, by the efforts of the industry with support from government scientific and financial capacities to engage in public relations campaigns, attacks on opponents, the maligning of unsympathetic scientific findings, intense lobbying, and the ability to disseminate information that is primarily sympathetic to the agricultural biotechnology industry. These strategies serve to constrain the discourse surrounding biotechnology in ways that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

In addition, the pro-GM crops discourse raises the issue about the relationship between the development of science and technology and capitalist social relations of production. One of the arguments posited by the government and industry in the construction of the discourse is the ostensibly ‘neutral’ development of science and technology under capitalist social relations of production and its corresponding specious and teleological claims about the putative capacity of science and technology to guarantee socio-economic progress. This perspective undermines the distinction between the development of science and technology in general and the development of science and technology under capitalist social relations of production, where the latter reflects the social relations under which it occurs. The appeal to science has provided government and industry a convenient strategy around which to circumscribe the social relations that underlie the pro-GM crops discourse and the adoption and production of GM crops. The development of science and (bio) technology is not a neutral affair. The conception of science and technology as asocial catalysts for progress independent of purposive human agency that benefits one group of people over another serves to obscure the social relations underlying the development of science and technology from the design and development stages of technological innovation. Such a conception not only relegates the social relations underlying new technologies to the instances of their application, but also casts their social effects on society as secondary and contingent. This suggests that scientists and technologists are the discoverers of laws and processes immanent in an exogenous natural realm. Progress is putatively rooted in the natural order of a world that triumphs over historical and social peculiarities. This discursive framing easily explains away social relations as unavoidable by-products of history's teleological march of progress that can be mitigated through the perspicacious applications of new technologies (Leoppky, 2005).

In this chapter I contribute to the academic literature by providing a different perspective from analyses that sever the relationship between the discursive and material in the construction of a pro-GM crops discourse. The pro-GM crops discourse is not a free-floating construction, but is materially implicated in the social relations of capitalism. Accordingly, the pro-GM crops discourse is embedded in and circulates among different institutions and subject positions. Such discursive struggles have material consequences for the development of agricultural biotechnology, the adoption and production of GM crops, multinational corporations, Canadian farming, the public, and the agro-food system in general.

Other authors contend that policy coordination, technical assistance, and training programs have helped produce, internationalize, and enforce a capitalist approach to the regulation of biotechnology, GM crops, and food safety, through the reductionist discourse of sound science. The internationalization of US standards has formed a major component of US agro-food trade strategies. Relying on appeals to sound science that posit US-based regulations as scientific and objective has been a critical component of rolling out neoliberal institutions in the US, Canada, and other developed and developing countries to harmonize biotechnology and food safety standards in line with US-led neoliberal and capitalist internationalization (Essex, 2008).

These developments have led some to question whether or not research and innovations are being compromised to protect IP interests (Glenna et al., 2015) and the role that a politicized science plays in the development of biotechnology (Herring, 2007; Stehr, 2004). Such perspectives stress that all research is partisan in one way or another because it involves questions about who controls, manipulates, and establishes decisions, facts, and knowledge. Scholarship is characterized by differences in the motives underlying epistemological choices of research topic and method, personal commitments to the fields studied, use of research findings in controversies, and positioning of results in wider debates (Galis and Hansson, 2012). Partisanship has also been associated with the composition of a government, its programmatic orientation, and the allocation of cabinet offices that affect agricultural biotechnology policy. Some authors argued that the regulation of GMOs is determined by the ideological orientation of governments and the presence of parties with a specific ideological background in the cabinet (Bäck et al., 2015). These studies raise concerns regarding the role political ideology plays in influencing views about science. While the generalization is often made that some sectors of society mobilize to defend the industrial capitalist order from the claims of environmentalists and some environmental scientists that the current economic system causes serious ecological and public health problems, some authors argued that such claims may oversimplify the issues in ways that lead to empirical inaccuracies. Further work is required that increases the accuracy and depth of our understanding of the relationship between political ideology and views about science which is crucial for addressing politicized science-based issues (McCright et al., 2013).

Other authors, while acknowledging the changes in government, industry, and the university system since the 1980s that have increasingly pressured academic and industrial scientists to align their research with the goals of national competitiveness, regional economic development, and marketplace opportunities, argued that a new framework for the study of science is needed that seeks to provide a balanced understanding of both the new restrictions associated with the increasing influence of the private sector on the scientific field and the new forms of citizen participation and public-interest science that are emerging in response. This perspective assumes that science is a partially autonomous field of power that is subject to influence from other fields but also possesses a degree of self-governance. This in part is due to the internal logic of the field and to the degrees of freedom that emerge from the unevenly countervailing powers exerted by economic, political, and civil society dynamics (Moore et al., 2011). Moreover, these tensions depend on various discourses that establish knowledge claims which simultaneously undermine the case for GM technologies as potential contributors to development and motivate opposition to GMOs. The diffusion of such claims has been made possible at the junctures of transnational networks, enabling the screening, weighting, theorizing, and diffusion of contentious empirical accounts (Herring, 2008; Suarez-Villa, 2003). The academic literature on the topic is vast and includes opposing narratives. Some authors attribute opposition to ignorance including problems of symbolism, quaint attitudes, and pagan beliefs (Bond, 1999; Braun, 2002; Gusterson, 2005; Herring, 2009) while other authors challenge such perspectives (Bonny, 2003; Bryan, 2001; Jasanoff, 2005; Priest, 2001). Other authors have traced such debates in the media coverage. These studies focus on the way varying attitudes play out in public perception, consumer choice, and discourse and language about GM crops (Cook, 2004; Gusterson, 2005; Kalaitzandonakes et al., 2004; Nelson, 2005; Pearson, 2006; Priest, 2001; Raby, 2014).

Chapter Six

Economic Implications of the Production of GM Crops for Farmers

6.1 Introduction

The last 25 years have seen the increasing adoption and production of GM crops such as canola, corn, soybean, and sugar beet in Canadian farming. This has been associated with the rise of multinational corporations, such as Monsanto, that invested heavily in private R&D to improve crop productivity through genetic modification. Patented GM seeds are sold to farmers in seed markets that have become highly consolidated. This has raised questions about whether or not biotechnology seed companies could exercise market power and price their seeds in a way that would reduce farm profit and bring agricultural biotechnology firmly within the purview of corporate control.

The purpose of this chapter is to assess the economic implications of the production of GM crops for farmers. I address the following questions: to what extent has agricultural restructuring affected farmers in Canada? Why has the federal government of Canada and the industry aggressively promoted the adoption and production of GM crops? What effect has the adoption of GM seeds and associated technology use agreements had on farming practices? Does the production of GM crops result in higher income for farmers? How are the economic implications manifested over time, in terms of production, subsidies, and trade export? I argue that the restructuring of the agricultural sector has encompassed a wide range of forces and conditions among which has been the dramatic increase of the adoption and production of GM crops. This has been associated with the rise and consolidation of a handful of multinational GM seed and agrochemical corporations aimed at economic growth in the agricultural sector in an era of competitive innovation in high-technology industries. The serious consequences for Canadian farmers have included stagnant net farm income despite increasing yields and gross income, higher farm expenses and debt, and stringent patent laws that limit farmers' autonomy.

To support the argument, I incorporate select responses from 19 interviews conducted between January and August 2015 with GM crop farmers (10 GM canola farmers, 5 GM corn farmers, and 4 GM soybean farmers), eight were members of the Canadian NFU and the remainder were independent farmers. The interviews with farmers allowed me to gain insights concerning the performance and economic impact of cultivating GM crops in the Canadian context. The analysis presented here is based on the average performance and economic impact recorded during interviews with farmers cultivating GM canola, corn, and soybean. Average performance and economic impact refers to the most common way that farmers reported these aspects based on their accounting records and partial budgets. A caveat is worth noting concerning this approach. Here, farmers are regarded as an undifferentiated category despite the fact that their individual economic positions vary: some own more land than others; some invest more capital than others; some employ more or less labour than others; some are economically more profitable than others; and so on (Lenin, 1967). My purpose is to make a general assessment of the net income for adopters, considering changes in yields, amounts and costs of inputs, and benefits that vary. The findings from my research are then compared with the findings of other relevant research from sources such as the NFU, the CBAN, Statistics Canada, PG Economics, and scientists conducting similar research. The NFU "is a direct-membership organization made up of Canadian farm families … [that] work together to achieve agricultural policies which will ensure dignity and security of income for farm families while enhancing the land for future generations" (NFU, 2015). The CBAN promotes food sovereignty and democratic decision-making regarding science and technology issues in order to protect the integrity of the environment, health, food, and the livelihoods of people in Canada. This is accomplished by facilitating, informing, and organizing civil society action, researching, and providing information to government for policy development (CBAN, 2016a). PG Economics "is a specialist provider of advisory and consultancy services to agriculture and other natural resource-based industries…areas of specialisation are plant biotechnology, agricultural production systems, agricultural markets and policy" (PG Economics, 2016).

The chapter is organized in the following way. In section **6.2 Agricultural Restructuring in Canada** I provide an overview of agricultural restructuring and the effects on Canadian farmers (section ***6.2.1 Effects of Agricultural Restructuring on Canadian Farmers***). In section **6.3 Biotech Farming in Canada** I examine the R&D investment in agricultural biotechnology, the impact of multinational agribusiness corporations; the introduction of GM canola, GM corn, and GM soybean into Canadian agriculture; and the implications for farmers. In section **6.4 Farm Level Economic Impact of GM Crops Production** I examine the effects of GM seed contractual agreements on farmers (section ***6.4.1 Commercial Seeds and Technology Use***

Agreements), the claims regarding GM crops and higher yields (section ***6.4.2 GM Crops and Yields***) and the impact on farm level income (section ***6.4.3 GM Crops and Farm Level Income***). In section **6.5 Conclusion** I draw out some conceptual implications and the contribution of the chapter to the academic literature.

6.2 Agricultural Restructuring in Canada

The agricultural sectors of developed economies have experienced significant changes over the last four decades as farm size, intensity, capitalization, and specialization have dramatically moved from conventional configurations to what has been referred to variously as the third agricultural revolution, the modernization of farming, the industrialization of farming, and the restructuring of farming (Bowler, 2014). At the farm level, the general model is one of a shift from small-scale (less than 50 hectares) or medium-scale (51 to 150 hectares), generally mixed-enterprise (including two or more crops), to large-scale farms (151 or more hectares) (FAO, 2014). This is characterized by increased labour substitution, capital investments in land, and an increase in off-farm inputs such as mechanical (energy intensive machinery) and biological (GM seeds and associated agrochemicals). At the agro-food system level, the process involves integration between fewer and fewer industrialized farms, and between agribusiness and government. The latter two 'beyond the farm gate' elements are the most important aspects, influencing and controlling the restructuring process (Troughton, 1986).

In the 1980s, trade wars, high debt, and drought brought significant structural changes to Canadian farming. The 'grain trade war' in the mid- and late-1980s between the US and the European Community caused Canadian grain prices to plummet. The prairie farming community, strapped by large debt and unprecedentedly high interest rates, sank into a depression whose scale paralleled that of the 1930s. Payments from the Western Grain Stabilization Act were low and continued to decline. The Government of Canada rallied to assist prairie grain farmers with the billion-dollar Special Canada Grains program in 1986-87 and it absorbed $400 million of the Farm Credit Corporation's debt. The Agricultural Credit Corporation of Saskatchewan also went heavily into debt in an effort not to force farmers off the land (Oleson, 1987).In addition, there was a marked shift since the mid-1980s in the policies of AAFC from practices that benefit Canadian farmers, such as developing new publicly funded varieties that are resistant to drought, disease, and pests, in favour of contracts and partnerships with private clients to meet exclusively private-sector needs such as patented agronomic inputs (Moore, 2002). AAFC policy objectives have become increasingly market oriented, ensuring supply of diverse food products, making the marketing system more effective, and increasing the economic viability of the industry in a context of free trade (Dakers and Forge, 2000).

In 1989, Canada and the US signed the Canada-United States Free Trade Agreement (CUSTA) which agreed to remove all tariffs and import restrictions over a ten-year period. In the case of wheat and barley it was agreed that border restrictions would be removed when subsidies were equivalent in both countries. End use certificates were used to prevent mixing of Canadian and US grains. The CUSTA also meant the end of the two-price wheat policy and eliminated the subsidy paid on grain shipped to the US through Vancouver. In order to counter massive grain subsidies in the world market, the Government of Canada implemented two new generations of farm income safety nets, the Gross Revenue Insurance Plan (GRIP) and the Net Income

Stabilization Account (NISA). The GRIP and NISA were financially supported by contributions from the federal and provincial governments and the farmer. The GRIP insured individual farmers' gross revenues from particular commodities in the short run. Also, it offered protection from natural hazards or from market risks beyond the control of producers. The NISA enabled a farmer to build up a fund to draw upon when his or her income fell below a specified figure. It marked a shift away from programs designed to stabilize farmers' returns for individual agricultural commodities to stabilizing the farmer's income from the whole farm enterprise (Turvey et al., 1997).

In 1993, the CUSTA was broadened to include Mexico in the North American Free Trade Agreement (NAFTA). Agriculture is the only section that was not negotiated trilaterally in the NAFTA; instead, three separate agreements were signed between each pair of parties. The Canada-US agreement contains significant restrictions and tariff quotas on agricultural products (mainly sugar, dairy, and poultry products), whereas the Mexico-US pact allows for a wider liberalization within a framework of phase-out periods. The NAFTA significantly increased Canada-US interdependence in agro-food trade. In 1984, 30% of Canadian agro-food exports went to the US; by 1993, the figure was 55% owing to increased exports of live animals, beef, and beverages. US imports into Canada rose from 55% of total Canadian agro-food imports in 1984 to 61% in 1993. Also, the creation of AAFC's Market and Industry Services Branch in 1993 was geared at strengthening the industry's competitiveness by obtaining a larger share of domestic and international markets (Dakers and Forge, 2000).

In the mid-1990s, the Cairns Group of Fair Trade Nations successfully forced agriculture onto the agenda of the Uruguay Round of negotiations on the General

Agreement on Tariffs and Trade (GATT) which eventually led to the World Trade Organization's (WTO) Agreement on Agriculture. All contracting parties agreed to reduce export subsidies by 21% in volume and by 36% in dollar terms, and to reduce domestic support by 20% over a six-year period beginning in 1995. The objective was to liberalize agricultural trade and open domestic agricultural markets to foreign competition. These multilateral negotiations posed significant challenges for Canada. On the one hand, Canada sought to open foreign markets to Canadian grains and oilseeds by new rules prohibiting export subsidies. The European Community and the US had successfully subsidized their grain exports to undercut Canada in grain-importing nations. On the other hand, Canadian negotiators were anxious to retain protection for domestic poultry, egg, and dairy producers by maintaining the right to restrict the volume of imports when supplies were managed domestically. Canada failed in its endeavour to maintain volume controls on supply-managed products and was forced to accept more imported dairy and poultry products; however, high tariffs on dairy and poultry imports in the medium term gave the sectors time to adjust to the future reality of lower tariffs and more competition from imported products. For Canada's grain and oilseeds sectors, the modest reduction in permissible export subsidies offered the prospect of better access to foreign markets even while it imperiled their own freight subsidies under the Western Grain Transportation Act. The 1995 federal Liberal budget announced an end to export grain subsidies, a decision dictated as much by budgetary restraint as by the new GATT requirements (Skogstad, 2008).

In addition was the negotiation of The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) at the end of the Uruguay Round of the GATT in 1994. Its inclusion was the culmination of a program of intense lobbying by the US, supported by the EU, Japan, and other developed nations. TRIPS essentially linked trade policy to IP standards therefore maximizing IP privileges. After the Uruguay Round, the GATT became the basis for the establishment of the WTO on 1 January 1995. The WTO superseded the GATT as the umbrella organization for international trade. Since ratification of TRIPS is a compulsory requirement of WTO membership, any country seeking to obtain access to the numerous international markets opened by the WTO must enact the strict IP laws mandated by TRIPS (Braithwaite and Drahos, 2000).

The Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) entered into force with the establishment of the WTO. Under the SPS agreement, the WTO set constraints on member-states' policies relating to food safety (bacterial contaminants, pesticides, inspection, and labelling) as well as animal and plant health (phytosanitation) with respect to imported pests and diseases. There are three standards organizations who set standards that WTO members should base their SPS methodologies on: the Codex Alimentarius Commission, World Organization for Animal Health, and the Secreatariat of the International Plant Protection Convention. The SPS agreement attempted to deal with non-tariffs barriers arising from cross-national differences in technical standards without diminishing governments' prerogative to implement measures to guard against diseases and pests (Buthe, 2008).

By the mid-1990s, budgetary constraints and new international trading rules had caused a significant reform of agricultural policies and altered the role of federal and provincial governments in Canada's agro-food sector. In the grains and oilseeds sector, the 1995 federal Liberal budget announced not only the termination of export freight assistance but also a 30% reduction in federal support for safety nets. A cut of the same magnitude was made in dairy price supports and their phasing out by the year 2000 announced. Earlier, cattle and hog producers fearing a backlash in the important US market, had opted for termination of their stabilization programs. The Government of Canada's share of total agro-food spending in 1994-95 was 55%, down from 64.5% in 1988-89. Provincial spending, especially in provinces like Quebec and Saskatchewan, had risen to make up the shortfall. Expenditure cuts to agricultural research, cost recovery initiatives in food inspection, and the elimination of duplication and overlap in federal and provincial programs and regulations cumulatively undermined the federal government's leadership role and the AAFC's capacity to devise national programs. By 1996, in place of one national farm 'safety net' for the grains and oilseeds sector, the decision was taken to allow provincial variations in crop insurance, whole farm stabilization, and provincial companion program coverage (Skogstad, 2008).

Despite various efforts at improving the economic viability of farming in Canada, the collapse of world commodity prices in 1997 resulted in a significant drop in net farm income. In response to this crisis, in December 1998 the Minister of Agriculture and Agri-Food announced a comprehensive federal program to provide $900 million in financial assistance to producers over two years through the Agricultural Income Disaster Assistance Program (AIDA Program), 40% of which was jointly funded by the provinces, and brought total assistance to $1.5 billion. The AIDA Program was linked to other income security programs, and AAFC's 1999-2000 Estimates noted the possibility of making the AIDA Program an element of long-term income protection (Dakers and Forge, 2000). In Canada and the US, multi-billion-dollar farm support programs have become the norm. In Canada, approximately $3 billion to $4 billion per annum in support payments is spent to cover large losses in farming. Large tax-funded transfers have become a structural element of agriculture in Canada, the US, the EU, Japan, and other countries (NFU, 2010).

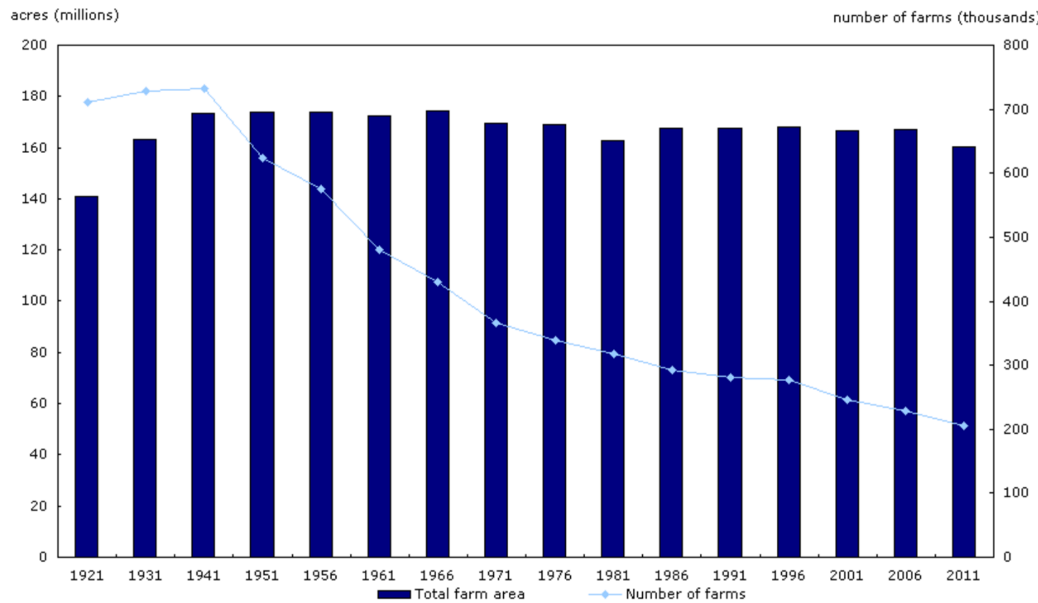
More recently, corporations and investors have been seeking greater control over Canada's agriculture and a bigger share of the wealth that farmers produce. Farmer autonomy and local control of land and production are threatened by excessive farm debt, input financing, the conversion of farmland to non-farm uses such as industrial use, resource extraction and urbanization, and by the trend of state and private investor acquisition of large tracts of farmland for speculative or political purposes. This has been accomplished through significant changes since 2010 to Canada's agricultural-related laws, policies and institutions. Such changes benefit agribusiness corporations, weaken farmers' market power, and increase farmer costs. This may be illustrated by the corporate control over commercial seeds as a result of Canada adopting the Plant Breeders Rights regime and related changes to seed regulation and cutbacks to conventional plant breeding programs. International trade deals such as CETA (Canada-European Union Comprehensive Economic and Trade Agreement), TPP (Trans-Pacific Partnership) and FIPPA (Freedom of Information and Protection of Privacy Act) entrench these threats through investor protection clauses enforced by investor-state dispute settlement provisions which allow corporations to sue governments if their ability to profit is diminished by changes in government regulations, laws, and policies (NFU, 2015).

Issues of export trade promotion, market development, and international competitiveness continue to be at the fore in Canadian agricultural policy. The traditional producer-centred focus has shifted to one which emphasizes partnerships between governments and all segments of the agro-food industry, with each assuming its share of financial responsibility for research, food inspection, and trade and market development. Such shifts in agricultural policy have not been effective at ensuring the survival of the family farm and rural communities. Many in the farm community fear that the Government of Canada's preoccupation with trade competitiveness and efficiency will necessitate even further consolidation and capitalization in the farm production sector, and further imperil the family farmer.

6.2.1 Effects of Agricultural Restructuring on Canadian Farmers

The effects of agricultural restructuring on Canadian farmers may be illustrated by the following data. According to Statistics Canada (2016c), the total number of census farms (any operation that produces agricultural products with the intention of selling them) began to decline after 1941. The largest five-year decline on record was from 1956 to 1961 when the number of farms fell by 16.4% or approximately 94,000 farms. Since 1991, the total number of farms decreased by 36.2% or 74,439 farms to reach 205,730 in 2011. While the number of farms has decreased, total farm area has remained stable (see Figure 6.1).

Figure 6.1: Number of Farms and Farm Area from 1921 to 2011



Source: Statistics Canada, 2016c

In 2011, the total number of farms represented a total farm area of 160.2 million acres (see Table 6.1).

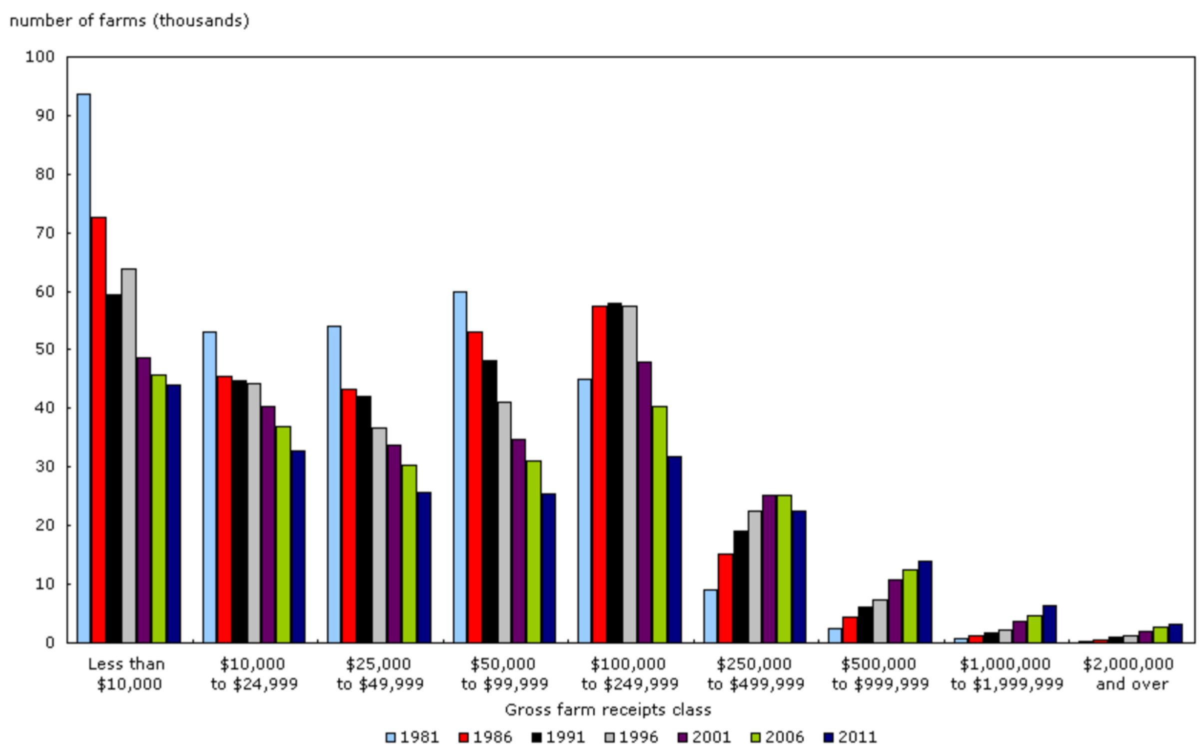
Table 6.1: Farms by Farm Area in 2011

Farm area	Number of farms	Number of farms as percent	Farm area (millions of acres)
Farms under 10 acres	12,991	6.3	10.1
Farms 10 to 69 acres	32,705	15.9	25.5
Farms 70 to 129 acres	24,205	11.8	18.8
Farms 130 to 179 acres	21,705	10.6	16.9
Farms 180 to 239 acres	11,719	5.7	9.1
Farms 240 to 399 acres	24,974	12.1	19.4
Farms 400 to 559 acres	15,053	7.3	11.7
Farms 560 to 759 acres	11,781	5.7	9.2
Farms 760 to 1,119 acres	13,413	6.5	10.4
Farms 1,120 to 1,599 acres	10,831	5.3	8.4
Farms 1,600 to 2,239 acres	9,222	4.5	7.2
Farms 2,240 to 2,879 acres	5,230	2.5	4.1
Farms 2,880 to 3,519 acres	3,482	1.7	2.7
Farms 3,520 acres and over	8,419	4.1	6.6
Total	205,730	100.0	160.2

Source: Statistics Canada, 2014a

The Canadian agricultural sector continues to restructure as many farms expand in scale of operation, consolidate, draw on technological innovations to enhance productivity, and augment their sales. This trend, consistent with the economies of scale characterizing parts of Canadian agriculture, is evident when examining farm numbers by gross farm receipts. From 1981 to 2011, the number of farms with gross farm receipts of $500,000 and over increased while the number of farms with gross farm receipts of $99,999 and less decreased (see Figure 6.2).

Figure 6.2: Number of Farms by Gross Farm Receipts at 2010 Constant Prices from 1981 to 2011



Source: Statistics Canada, 2016c

According to Statistics Canada (2016c), Canada had 9,602 farms with $1 million or more in gross farm receipts reported in 2010. While these farms are still a relatively small proportion of all farms, they increased significantly, from 3.2% of the total number of farms and 42.8% of gross farm receipts in 2005 to 4.7% of the total number of farms and 49.1% of gross farm receipts in 2010 (at 2010 constant prices). The number of farms reporting $1 million and more (at 2010 constant prices) in gross farm receipts increased by 31.2%, while the number of farms reporting less than $1 million decreased by 11.7%. Lastly, the number of farms with gross farm receipts reporting $2 million and over (at 2010 constant prices) increased by 22%. Although this category has only 3,298 farms representing 1.6% of the total number of farms, they reported approximately one-third of all gross farm receipts (see Table 6.2).

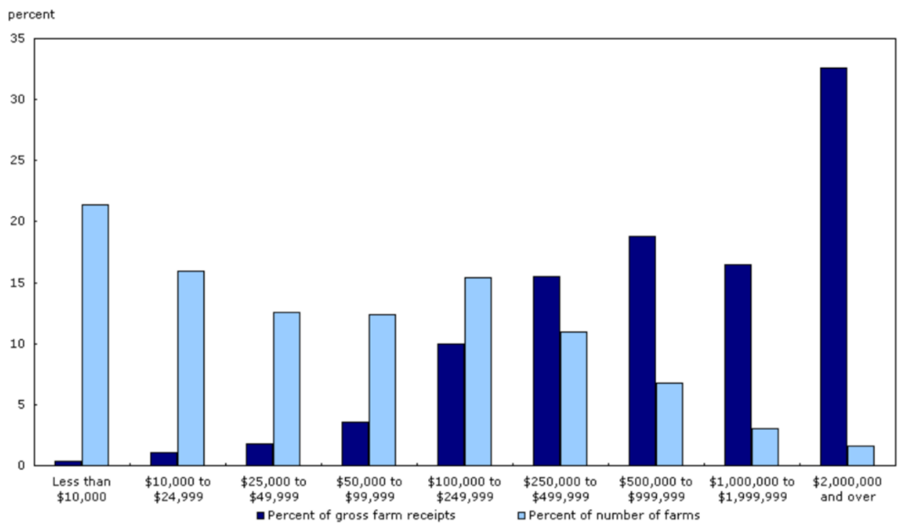
Table 6.2: Number of Farms by Gross Farm Receipts at 2010 Constant Prices in 2006 and 2011

Gross farm receipts	Number of farms		Percent change, 2006 to 2011
	2011	2006	
Less than $10,000	43,954	45,749	-3.9
$10,000-$24,999	32,853	36,971	-11.1
$25,000-$49,999	25,764	30,227	-14.8
$50,000-$99,999	25,455	31,119	-18.2
$100,000-$249,999	31,670	40,382	-21.6
$250,000-$499,999	22,455	25,108	-10.6
$500,000-$999,999	13,977	12,499	11.8
$1,000,000-$1,999,999	6,304	4,614	36.6
$2,000,000 and over	3,298	2,704	22
Total	205,730	229,373	10.3

Source: Statistics Canada, 2016c

Farms with $500,000 and over in gross farm receipts accounted for 11.5% of farms in 2011 and 67.9% of the total gross farm receipts (see Figure 6.3).

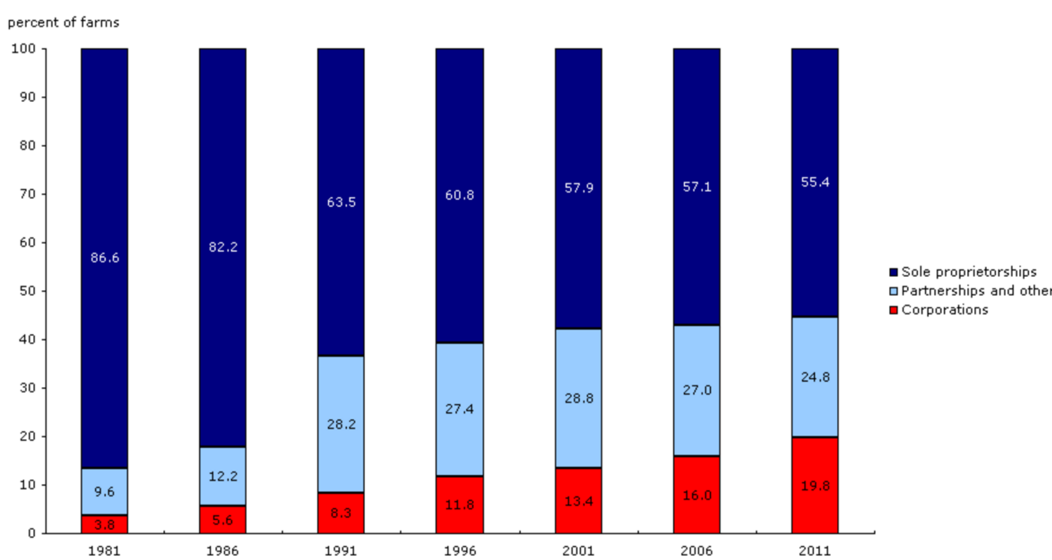
Figure 6.3: Proportion of Gross Farm Receipts and Farm Numbers by Receipts Class in 2011



Source: Statistics Canada, 2016c

From 1981 to 2011, there has been an increase from 3.8% to 19.8% in the proportion of farms that were incorporated, and a decrease from 86.6% to 55.4% in the proportion of farms that were sole proprietorships (see Figure 6.4).

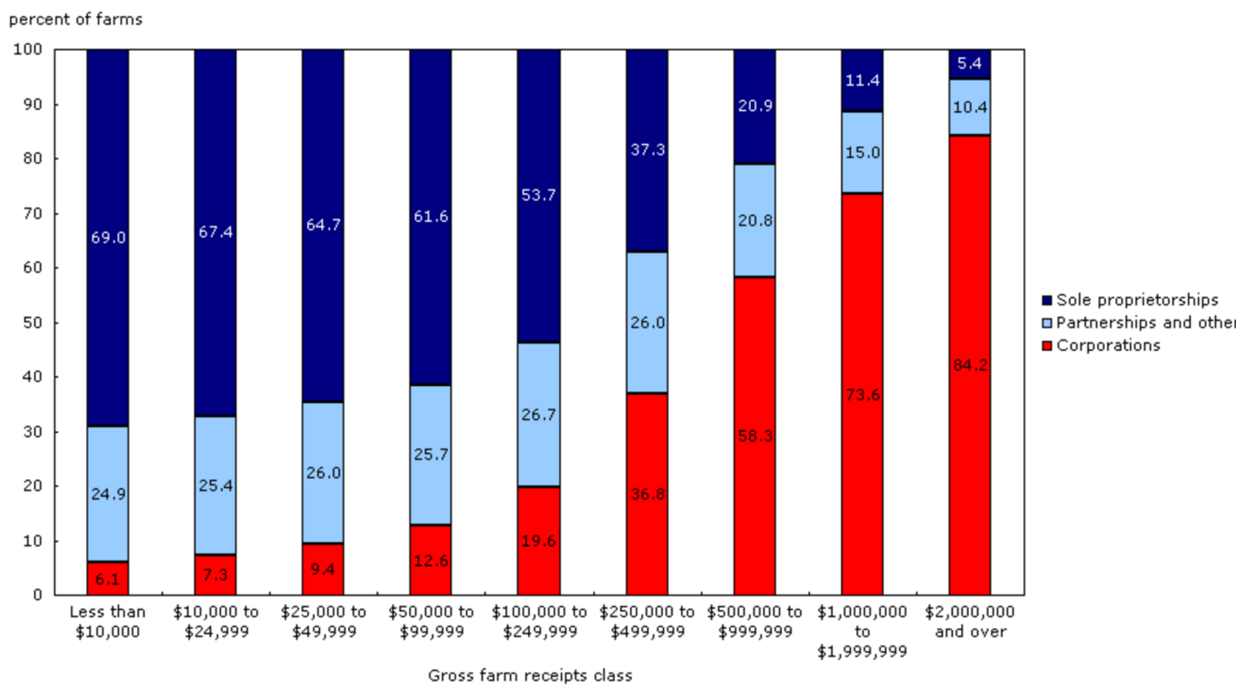
Figure 6.4: Operating Arrangements of Farms from 1981 to 2011



Source: Statistics Canada, 2016c

There is a tendency for the proportion of farms operating as sole proprietorships as well as those operating as partnerships or other to decline as gross farm receipts increase. Also, farms in the higher gross farm receipts category are more likely to be incorporated (see Figure 6.5). In addition, 77.2% of million-dollar farms were incorporated compared with 19.8% of all farms. Family corporations represented 66.3% of million-dollar farms compared with 17.4% of all farms, and non-family corporations represented 10.9% of million-dollar farms compared with 2.4% of all farms.

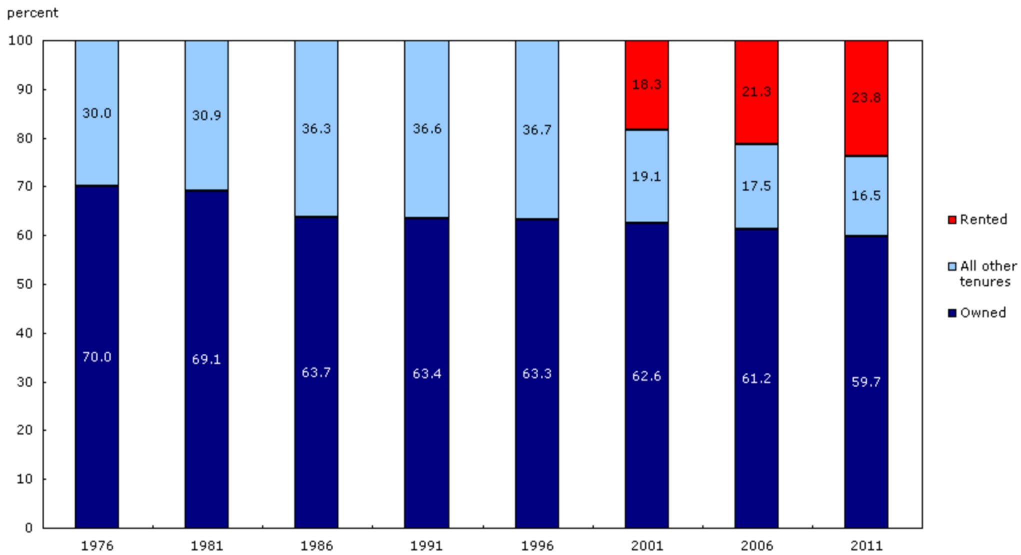
Figure 6.5: Operating Arrangements by Gross Farm Receipts in 2011



Source: Statistics Canada, 2016c

From 1976 to 2011, there has been a decrease from 70% to 59.7% in the proportion of land owned by farmers, and an increase from 30% to 40.3% in the proportion of land rented and other tenure arrangements (see Figure 6.6).

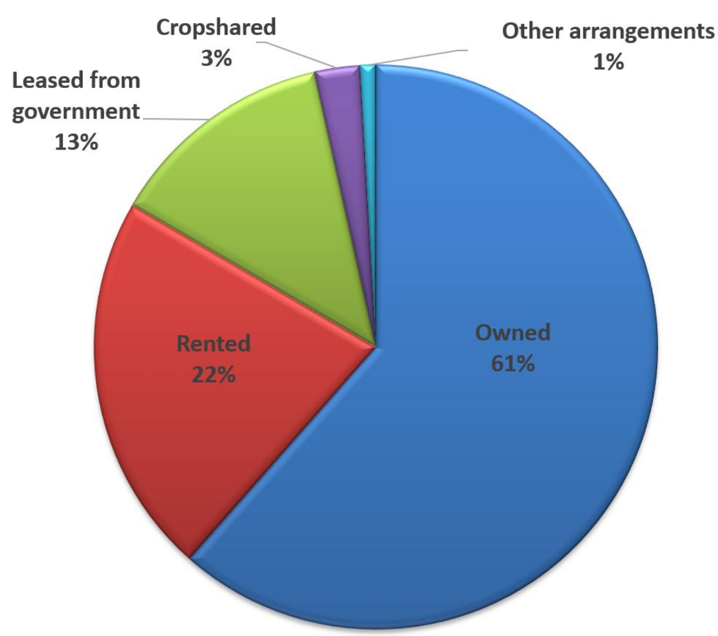
Figure 6.6: Land Tenure as a Proportion of Total Farm Area from 1976 to 2011



Source: Statistics Canada, 2016c

In 2011, 61.5% of the total land in agriculture was owned by those who operated it (see Figure 6.7).

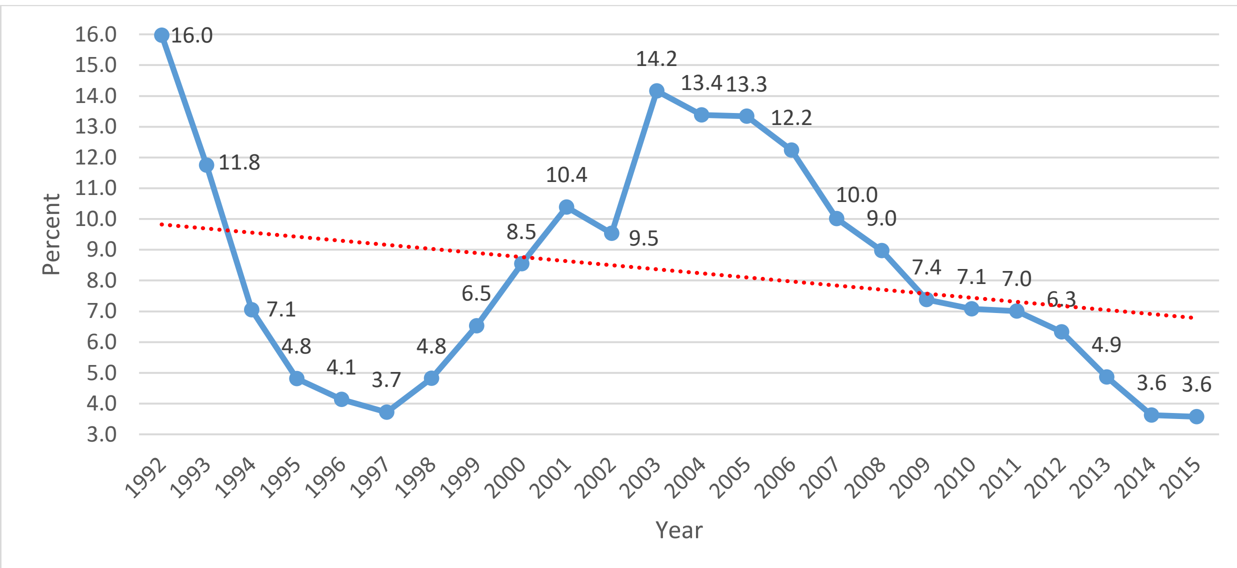
Figure 6.7: Tenure Composition of Total Agricultural Land in 2011



Source: Statistics Canada, 2016c

Gross farm receipts in Canada were $51.1 billion in 2010, up 3.9% from $49.2 billion (at 2010 constant prices) in 2005. Gross farm receipts come from the sale of farm commodities and include payments from government-sponsored programs. Farmers contribute to these programs by paying premiums. In general, there has been a decrease in direct program payments to farmers from a peak of 16% of gross farm receipts in 1992 to 3.6% in 2015. The value of direct program payments in 2015 was $2.1 billion (see Figure 6.8).

Figure 6.8: Receipts from Direct Program Payments in Percent from 1992 to 2015



Source: Statistics Canada, 2016f

Three farmers from the NFU commented on the restructuring of farming that generations of farmers in Canada have faced during different periods from the 1950s to the 1990s. These comments highlighted a shift in policies that favour Canadian farmers to policies that favour the viability of the industry amidst funding cuts and difficult market conditions.

> My father was involved in different organizations in the 50s and 60s that really tried to secure the future of farming. There were lots of institutions

that came out of this, like the Canada Grain Act, the Canadian Wheat Board, Agriculture Canada [renamed Agriculture and Agri-Food Canada], that were very much committed to the financial well-being of farming and farmers. This goes back several generations, you know, Canadian government wanted to establish an agricultural economy in western Canada and farmers were a big part of that and previous generations needed a kind of minimum income to secure their livelihood. Even when it came to things like technology, different institutions, even Agriculture Canada was dedicated to doing research on breeding, on pests, and other agronomic concerns that farmers had to enhance their economic livelihood and provide protection from big business. But those days are gone now, there is less support for farming and so many have just gone under or gave up all together. Farming is really a tough business and the support is not there like it used to be (NFU Farmer 3).

Well, there were many changes in farming especially after the Conservatives came into power in the 1980s. For one thing, we were being told by Agriculture and Agri-Food Canada, that free trade was coming and we had to be more competitive. There were a lot of farmers that were planting new crops and trying to diversify their production and there were others that were taking on work outside of farming all together. In some cases farmers sold their farms to bigger operations that had the kind of money you need to improve equipment and become more efficient. You know, the whole industry was changing, farming was less and less about what farming is supposed to be about, which is producing good crops, and more and more about big business and doing whatever it takes to stay competitive (NFU Farmer 4).

The late 1990s was a really awful time for many farmers especially out here in the west. I personally knew quite a few farmers that simply went out of business. I mean you just couldn't make ends meet unless you were well established. Despite everything that was happening the government had no real solutions other than providing some kind of assistance, but basically it was business as usual. Regardless of the fact that the changes that they wanted us to make in the 1980s, this whole thing about free trade and being more competitive, did not help the situation much, things became even worse by the end of the 1990s, but the emphasis remained the same as before: do more with less because the government does not have the money it used to for farming, be more competitive because of globalization, you know, the same thing they said in the 1980s except we were in much worse shape now than we were back then (NFU Farmer 5).

In summary, the analysis in this section provides an overview of the structural changes in Canadian farming and the effects this has had on farmers. Agricultural restructuring has resulted in changing and demanding economic, technological, and market environments for farmers in Canada. In response, the Government of Canada has placed greater emphasis on making the sector more market-responsive, less dependent on subsidies, and able to compete internationally.

6.3 Biotech Farming in Canada

Given the restructuring of the Canadian agricultural sector, the development, adoption, and production of GM crops has been in part a critical component of the drive towards international competitiveness, productivity, economic growth, and innovation. This has been substantiated by significant expenditures on biotechnology R&D (see Table 6.3) and science and technology R&D by the Canadian federal government (see Table 6.4).

Table 6.3: Annual Federal Government Science and Technology R&D on Biotechnology Expenditures

Year	**Amount** (thousands of dollars)
2003/2004	756,239
2004/2005	804,161
2005/2006	864,830
2006/2007	880,087
2007/2008	920,548
2008/2009	936,827

Notes and sources: this table contains the most current data available from Statistics Canada on biotechnology R&D expenditures. Disaggregated data following 2008/2009 is not available, (Statistics Canada, 2010, 2012b).

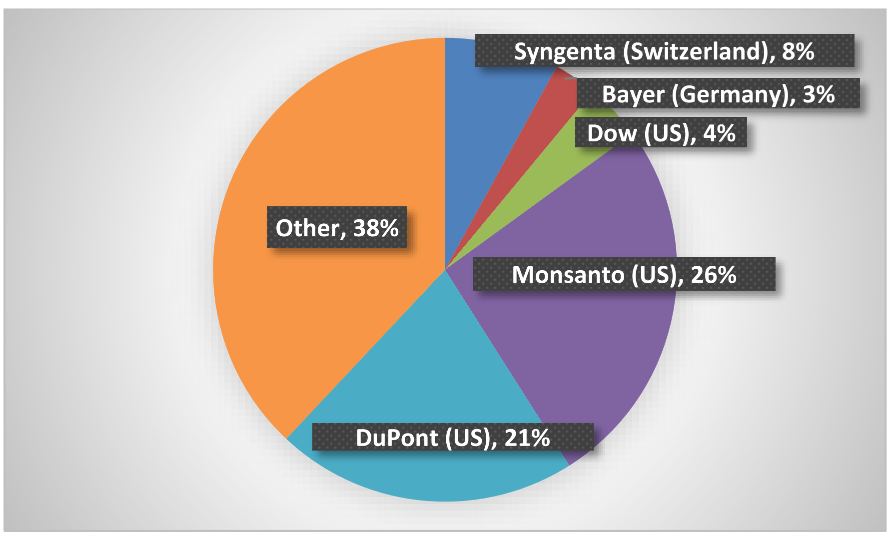
Table 6.4: Annual Federal Government Science and Technology R&D and Related Activities Expenditures

Year	**Amount** (millions of dollars)
2003/2004	8,765
2004/2005	8,934
2005/2006	9,449
2006/2007	9,633
2007/2008	10,176
2008/2009	10,573
2009/2010	11,614
2010/2011	12,014
2011/2012	11,395
2012/2013	11,166
2013/2014	10,868
2014/2015	10,281

Source: Statistics Canada, 2014b

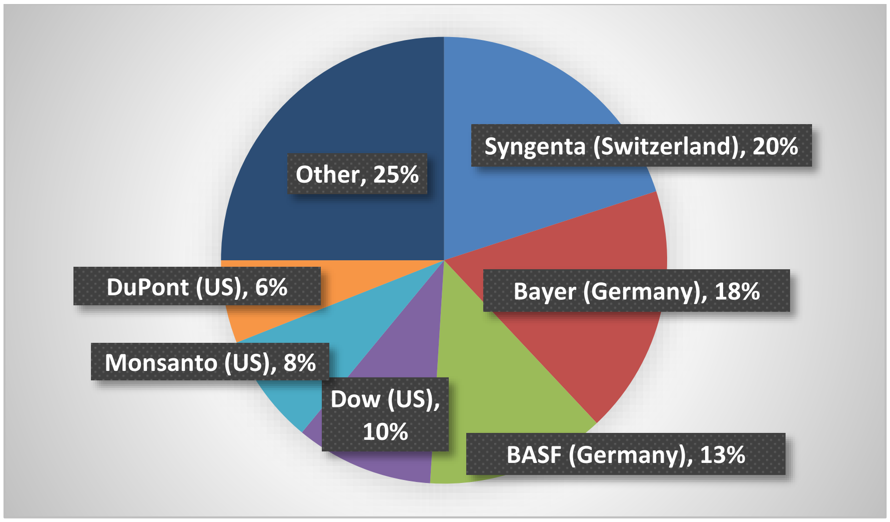
In addition has been the important role of a handful of multinational corporations that have captured the global proprietary GM seed and agrochemical (herbicides, insecticides, and fungicides) markets. The world's top 11 GM seed companies: Monsanto (US), DuPont (US), Syngenta (Switzerland), Groupe Limagrain (France), Land O'Lakes (US), KWS SAAT SE (Germany), Bayer (Germany), Dow (US), Sakata (Japan), DLF-Trifolium (Denmark), and Takii (Japan), accounted for approximately 37% of the global proprietary seed market in 1996, which increased to 55% in 2007, and 62% in 2009. In 2009, the top three companies (Monsanto, DuPont, and Syngenta) controlled 45% of the global proprietary seed market. Monsanto, which is the largest player in the industry, controlled 23% of the global proprietary seed market. Also, an estimated 87% of the total GM seeds cropland area was planted with Monsanto products either directly or indirectly through licences to other companies. In terms of proprietary seed revenues, in 2009 sales for the top 11 companies were: US$19.7 billion (62%) of the US$32 billion global proprietary seed market, and the top three companies controlled US$14.5 billion (45%). Monsanto controlled US$7.3 billion (23%) of the US$32 billion global proprietary seed market (Peekhaus, 2013, 42-44). As of 2013, the world's top three seed companies, Monsanto, DuPont, and Syngenta accounted for 26%, 21%, and 8% respectively or 55% collectively of the global proprietary seed market, while the top three agrochemical companies, Syngenta, Bayer, and BASF accounted for 20%, 18%, and 13% respectively or 51% collectively of the global agrochemical market. Collectively, the top six companies: Monsanto, DuPont, Syngenta, Bayer, Dow, and BASF accounted for 65% of the global proprietary seed market, and 75% of the global agrochemical market with sales of seeds, agrochemicals, and GM traits exceeding $65 billion per annum (see Figure 6.9 and Figure 6.10).

Figure 6.9: Global GM Seed Market Share



Source: ETC Group, 2015

Figure 6.10: Global GM Agrochemical Market Share



Source: ETC Group, 2015

The use of patented GM traits has helped facilitate corporate consolidation in the seed market. This has resulted in an oligopolistic market structure in which the largest actors are able to increase prices, narrow genetic diversity in crops, and stagnate innovation. A related consequence of consolidation is that the major corporations that control the global seed and agrochemical markets now also largely determine the priorities and future direction of agricultural research. For example, the top six companies account for 75% of all private sector seed and agrochemical research (ETC Group, 2015).

Following vigorous marketing of GM canola, soybean, and corn (the three largest GM crops cultivated in Canada), Monsanto received regulatory approval from Health Canada to market glyphosate tolerant canola for food use in 1994. Glyphosate tolerant canola was developed through a specific genetic modification of *Brassica napus* to be resistant to the activity of glyphosate herbicides (Health Canada, 1999). Monsanto's glyphosate tolerant soybean received regulatory approval from Health Canada to market for food use in 1996. The glyphosate tolerant seeds, marketed as ‘Roundup Ready’, are genetically engineered to produce crops capable of surviving post-emergent applications of ‘Roundup’, a broad-spectrum non selective systemic herbicide that is sprayed and absorbed through the leaves of the plants (Health Canada, 2000). Monsanto’s insect resistant corn received regulatory approval from Health Canada to market for food use in 1997. Insect resistant corn is genetically engineered to contain a gene derived from the naturally occurring soil bacterium *Bacillus thuringiensis* (crops containing this gene are commonly referred to with the prefix Bt, for example, Bt-corn). The bacterium produces a crystal protein that destroys the digestive tract of certain insects when ingested and mixed with stomach acids (Health Canada, 1997).

GM canola is grown by 43,000 farmers in Canada, accounting for more than 98% of all canola, mostly in the western provinces of Alberta, Saskatchewan, and Manitoba. Also, British Columbia, Ontario, and Quebec grow a substantial amount of the crop. This is the result of new GM varieties that are pushing the boundaries of where the crop may be cultivated. The biological and agronomic characteristics of canola make it a weed- and disease-prone crop, which has made canola farmers more inclined to accept GM varieties and associated agrochemicals. Innovations in canola, through the introduction of herbicide tolerance, has reduced farmers’ costs and the use of natural resources in its production. In addition, GM varieties have allowed farmers to substitute conventional tillage with no-till seeding techniques or conservation tillage. No-till is less ecologically disruptive as specialized machinery is used to slice a thin slit into the soil to deposit seeds. Conservation tillage is also less disturbing of soil ecology as the depth of furrows is between that of no-till and conventional tillage. Both production methods reduce overall machinery investment, labour needs, and energy requirements and have comparable or better yields and net returns than conventional tillage methods. Approximately 15% of the GM canola crop is consumed in Canada in various forms (e.g., approximately 50% of the vegetable oil consumed by Canadians is canola oil). The remainder 85% of canola seed, oil, and meal are exported to destinations such as the US, Japan, Mexico, and China. Annually, Canadian-grown GM canola contributes $19.3 billion to the economy, including more than 249,000 Canadian jobs and $12.5 billion in wages (CCC, 2016).

GM corn plantings have been steadily increasing, accounting for 83% of all corn planted in Canada. Quebec and Ontario are the primary corn-growing regions, accounting for 90% of total Canadian corn areas. Also, Monsanto announced its intention to invest $100 million over the next ten years to produce corn hybrids that could be widely grown across an estimated 10.5 million hectares in western Canada. The corn hybrids will have relative maturities in the 70 to 85 day interval, making them suitable for cultivation in the colder climate of the Canadian prairies. GM soybean accounted for more than 90% of total soybean acreage in 2007. Ontario and Quebec accounted for approximately 69% of total soybean acreage, while Manitoba's share has risen from 8% in 2007 to 23% in 2013 (Dessureault and Lepescu, 2014).

The increasing demand for patented GM seeds has resulted in the deregistering and removal from the market of conventional varieties and the virtual cessation of public breeding of the major crops that have GM varieties in Canada (corn, canola, and soybean). For example, in 2000 96 out of the 120 (80%) of the registered varieties of canola were conventional seeds. By 2007, only five of the registered varieties of canola were conventional seeds. Also, since 2005 the federal government has shut down or decreased the funding of a number of public breeding institutions in Canada. Research stations that have been shut down include: the Delhi Research Station in Ontario, the Herve J. Michaud Experimental Farm in New Brunswick, the Kamloops research centre in British Columbia, and the Cereal Research Centre in Manitoba (CBAN, 2015).

As plant breeding increasingly shifted into the private sector, farmers payed more for GM seeds that are less adapted to their regions and less resilient to environmental change (NFU, 2013). As conventional varieties are phased out, and because GM traits are bred into conventional varieties that already have the best performance characteristics, buying GM seeds is often the only way that farmers can access modern, high-yielding varieties. This has diminished the choices available to farmers, while strengthening the control of major corporations (ETC Group, 2015). In addition, the profits generated from private breeding return to shareholders instead of farming communities and public breeding programs that developed the conventional crops which have genetic sequences. The most profound example in Canada is the development of rapeseed/canola (see Phillips and Khachatourians, 2001).

The Canadian farmers that participated in this research entered contracts with Monsanto to cultivate GM canola, soybean, and corn. The contract between the farmer and Monsanto significantly limits the farmer's rights to the purchased seeds through a 'no saved seed' provision which prohibits saving seeds and/or reusing seeds from GM crops and requires farmers to purchase GM seeds on an annual basis (Fernandez-Cornejo and McBride, 2002). This significantly alters the practices of generations of farmers who have selected, saved, exchanged, sold, and reused seeds. The value of a seed is realized not just in one harvest, but in the seeds it produces for future crops and the material it provides for future breeding. Patent protection over new genetic sequences is one legal mechanism that takes ownership of seeds out of the hands of farmers and allows corporations to capture value from them. In practice, this means that patents allow the corporation that developed a GM trait to forbid farmers from saving and replanting seeds with that trait, and public breeders from further selecting or developing. Multinational GM seed companies with spend billions of dollars on patents and patent lawyers, and on policing farmers (CBAN, 2015).

One of the most widely publicized patent infringement cases stemming from the unauthorized saving of GM canola seeds was tried in the Canadian courts. In the case of *Percy Schmeiser and Schmeiser Enterprises Limited v Monsanto Canada Incorporated and Monsanto Company*, canola farmer Schmeiser was sued by Monsanto for saving and planting GM seeds produced from pollen that had blown onto his fields from a neighbouring farm. Schmeiser did not have contract with Monsanto. The court found that Schmeiser planted seeds saved from a field onto which pollen from GM canola had blown and engaged in these activities knowingly. This violated the patent Monsanto held on the GM canola seeds. Schmeiser was required to deliver to Monsanto any remaining saved seeds and pay Monsanto the profits earned from the crops plus interest (CBC News Online, 2004).

Also, the contract between the farmer and Monsanto contains a binding arbitration clause that requires all conflicts arising from the performance of the seed or technological traits in the seed to be resolved through arbitration. This binding arbitration clause precludes farmers from filing lawsuits. In addition, the farmer is constrained in terms of the time frame within which s/he must raise a dispute. Under the contract, the farmer is typically given as little as 15 days from the day that the problem is first observed to file a complaint with Monsanto. Lastly, the contract contains a clause that limits the liability of Monsanto for any losses, injury or damages resulting from the use of their GM product. Under such a clause, if the use of GM seeds has a negative impact on another aspect of the farmer's operations, the farmer is precluded from recovering any damages from the company in the event the use of the product causes harm (Fernandez-Cornejo and McBride, 2002). A farmer in an interview commented on the economic costs and breeder restraints associated with entering a contract with Monsanto.

> The contract binds you to Monsanto and once you make that commitment you don't realize what exactly you're getting yourself into. It's not as simple as just buying a bag of seeds, there are other costs as well. There is a kind of learning curve that takes place and you don't make money if you don't know how to use the technology. There's no 'money-back guarantee'; you are basically on your own. There were some years that I was using GM corn and quite frankly did not make much money. Also, if you want to keep using the GM seeds you are basically committed to buying seeds every year, and if you reuse seeds you can get sued. Monsanto wants to make money so they are always trying to sell you something better, new seeds and new varieties, for more money of course. So, you have to be careful because you are in a contract with a big corporation and there's a sense that you have a new partner in your business and there are rules that you have to go by, well their rules, if you want to make money in farming. The old days of saving and trading seeds are gone; things are more complicated now (Independent Farmer 1).

In summary, significant investments from the Government of Canada in the development of biotechnology and science and technology R&D as well as the regulatory approval of various GM crop varieties has spurred the development of the agricultural biotechnology industry in Canada. This has been associated with the rise and consolidation of a handful of multinational corporations that have effectively marketed GM crop varieties. The outcome has been the significant adoption and production of GM canola, corn, soybean, and sugar beet in Canadian agriculture and related stringent contractual agreements that protect corporate IP rights and limit farmers' abilities to select, save, exchange, sell, and reuse seeds.

6.4 Farm Level Economic Impact of GM Crops Production

6.4.1 Commercial Seeds and Technology Use Agreements

In Canada, there has been an exponential rise in the cost of commercial seed compared to other farm expenses. For example, the annual rate of increase of commercial seed cost from 1986 to 2015 was 15% compared to 9.6% for fertilizer and lime (see Table 6.5).

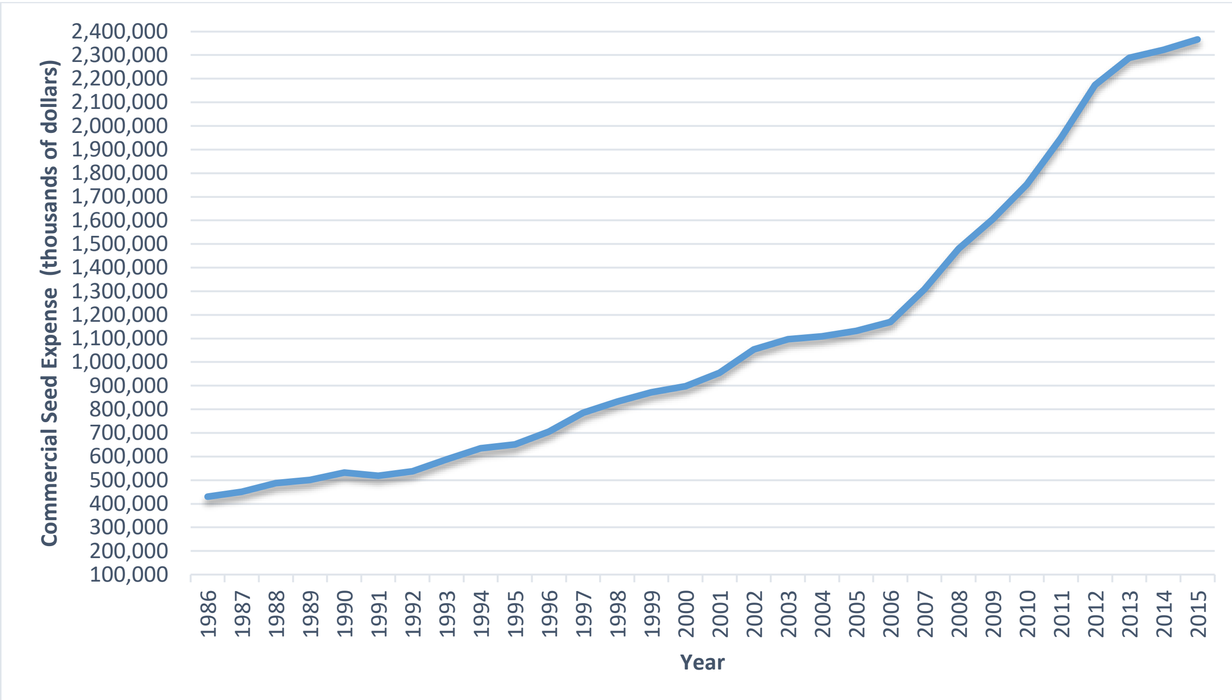
Table 6.5: Annual Rate of Increase in Farm Expenses from 1986 to 2015

Farm Expenses	Annual Rate of Increase in Percent
Property taxes	2.8
Wages including room and board	7.2
Interest	2.0
Electricity	5.1
Heating	5.7
Machinery fuel	3.5
Fertilizer and lime	9.6
Pesticide	9.5
Commercial seed	15.0

Source: Statistics Canada, 2016a

In 2015, commercial seed cost accounted for 5.4% of total farm expenses. In absolute terms, commercial seed cost for increased from approximately $430 million in 1986 to approximately $2.4 billion in 2015, with a marked escalation in cost following the introduction of GM seeds in the mid-1990s (see Figure 6.11).

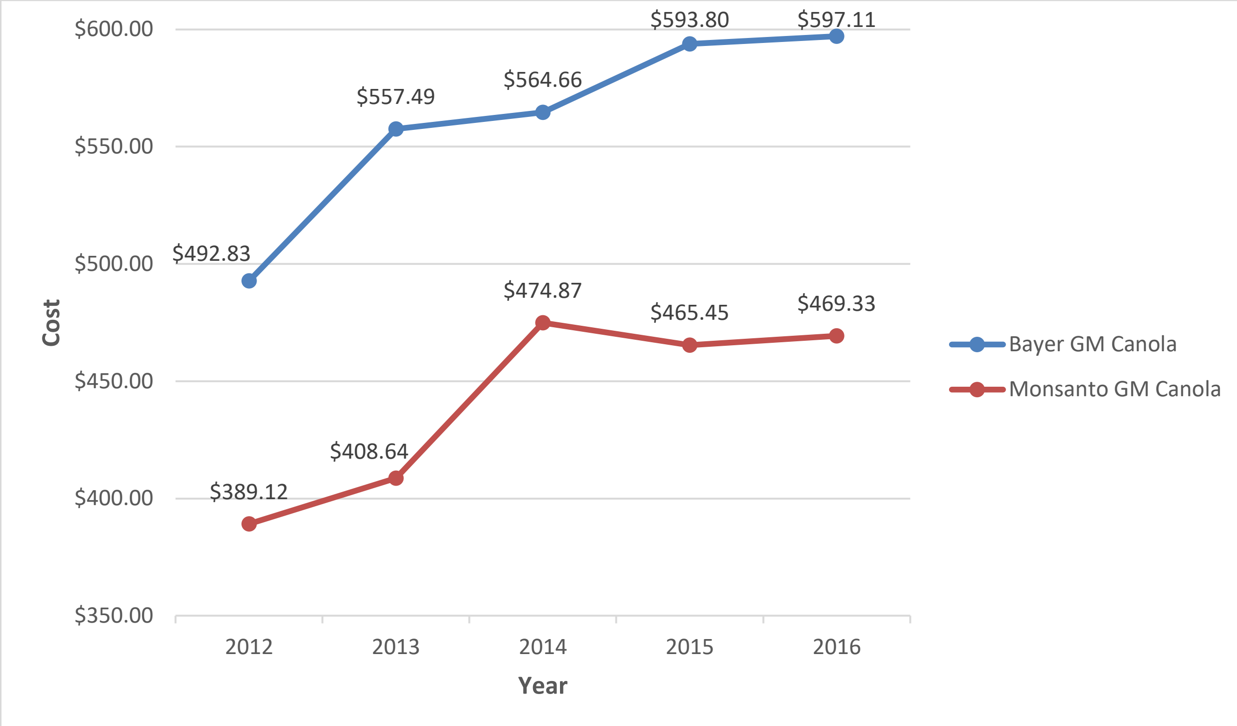
Figure 6.11: Canadian Farmer Commercial Seed Cost from 1981 to 2014 in Thousands of Dollars



Source: Statistics Canada, 2016a

More specifically, the per-acre seeding cost of GM canola has been rising at a faster rate than the per-acre seeding cost of conventional canola. For example, in Alberta the per-acre seeding cost of GM canola increased from approximately $20/acre in January 2002 to approximately $45/acre in January 2011 compared with the per-acre seeding cost of conventional canola which increased from approximately $15/acre in January 2002 to approximately $26/acre in January 2011 (NFU, 2013). More recent data from the Government of Alberta confirm the continuing rise in the cost of GM canola since 2012. For example, the cost of Bayer GM canola per 22.7 kg bag increased from $492.83 in January 2012 to $597.11 in January 2016 and the cost of Monsanto GM canola per 22.7 kg bag increased from $389.12 in January 2012 to $469.33 in January 2016 (see Figure 6.12).

Figure 6.12: Seeding Cost for a 22.7 kg Bag of GM Canola from 2012-2016



Source: Government of Alberta, 2016

In addition to seed cost, farmers were required to sign and pay for a Technology Use Agreement (TUA) fee. For example, in 2011 Monsanto charged GM canola farmers a $15/acre TUA fee, which amounted to approximately $261 million in Canada over and above seed cost (NFU, 2013). As of the 2013 crop year, however, Monsanto announced details of its plans to change the way farmers purchase Roundup Ready canola to a seamless 'in-the-bag' model with one price that combines the cost of the seed and the technology fee. This model has also been used for other crops such as GM soybean and GM corn (Monsanto, 2012). Although there will no longer be a separate TUA fee, farmers will still be required to sign an agreement that stipulates stringent 'stewardship responsibilities' that accompany all of Monsanto's seed varieties and are outlined in the Technology Use Guide (TUG). Some of the stewardship responsibilities include:

> Bt crop farmers implement an insect resistant management program; farmers use purchased seeds for a single commercial crop; farmers are prohibited from giving another person or entity seeds for planting; farmers are not allowed to plant seeds resulting from the crop in subsequent years; seeds are not to be used for crop breeding, research, generation of herbicide registration data or seed production; Monsanto limits its liability for any loss incurred from using the product and dictates how farmers must proceed if they launch a claim; farmers are required to provide full access rights to their fields and records to conduct a technology protection audit; and Monsanto reserves the right to enjoin farmers found in breach of contract from using or selling its seeds (Monsanto, 2016a).

Moreover, the TUG recommends using Roundup Ready seeds in conjunction with Roundup glyphosate herbicide products sold by Monsanto. Although Monsanto allows farmers to use another Canadian approved glyphosate herbicide, this practice is discouraged in the TUG wherein it is noted,

> MONSANTO DOES NOT MAKE ANY REPRESENTATIONS, WARRANTIES OR RECOMMENDATIONS CONCERNING THE USE OF PRODUCTS MANUFACTURED OR MARKETED BY OTHER COMPANIES WHICH ARE LABELED FOR USE ON CROPS CONTAINING ROUNDUP READY® TECHNOLOGIES. MONSANTO SPECIFICALLY DISCLAIMS ALL RESPONSIBILITY FOR THE USE OF THESE PRODUCTS IN CROPS CONTAINING ROUNDUP READY TECHNOLOGIES. ALL QUESTIONS AND COMPLAINTS ARISING FROM THE USE OF PRODUCTS MANUFACTURED OR MARKETED BY OTHER COMPANIES SHOULD BE DIRECTED TO THOSE COMPANIES (Monsanto, 2016, 9, caps in original).

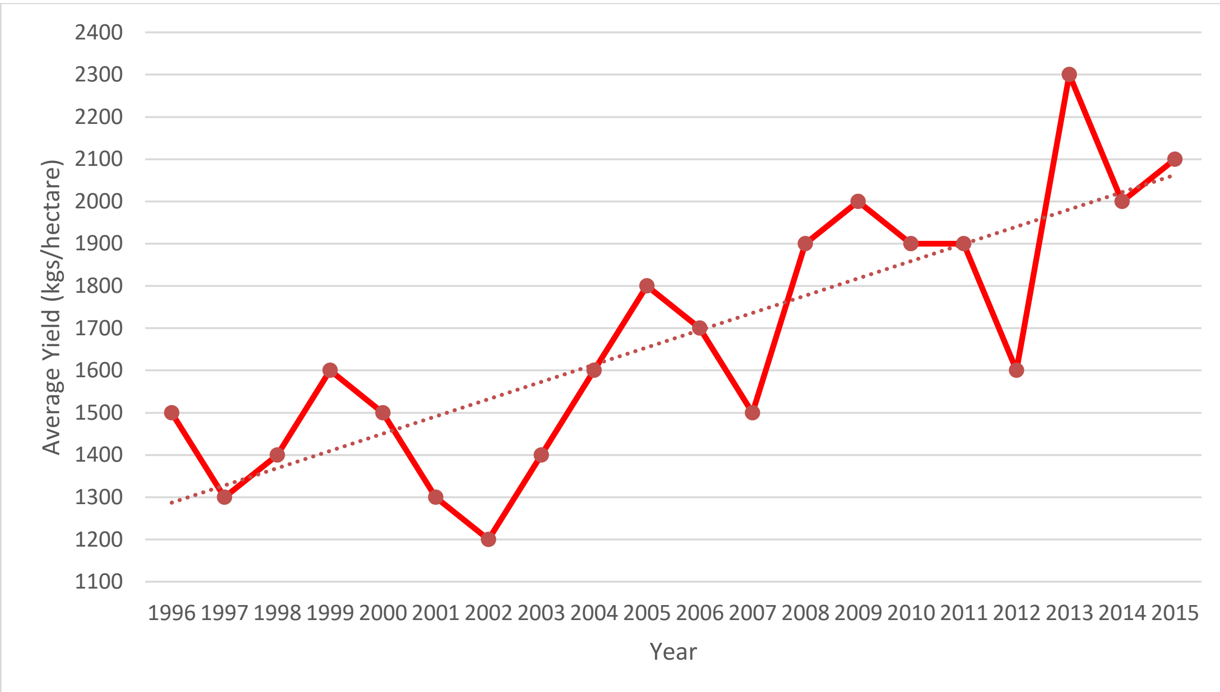
Since technology fees comprise a significant portion of the overall cost of GM seeds, there is pressure on farmers to purchase and apply only Roundup formulations on their glyphosate-resistant crops.

6.4.2 GM Crops and Yields

One of the common claims to justify the adoption and production of GM crops is that they produce higher yields than conventional crops. This claim is then linked to the assumption that higher yields result in higher incomes for farmers. In this section I show that despite the positive impact derived from a combination of enhanced productivity and efficiency gains associated with the adoption and production of GM crops, farmer expenses and debt have increased while farmer income has remained stagnant.

The 19 Canadian farmers that participated in this research reported that on average there has been a general increase in yields as a result of producing GM canola, corn, and soybean. The nine farmers that adopted herbicide-tolerant canola reported higher yield increases for the initial years of production followed by lower yield increases for the later years of production compared with conventional canola. These results are consistent with other studies (see, for example, Brookes and Barfoot, 2015; Carew and Devadoss, 2003; CBAN, 2015b; Gusta et al., 2011; Malla and Brewin, 2015). According to Brookes and Barfoot (2015), from 1996 to 2003 there was an average yield increase of 10.7% for herbicide-tolerant canola compared to conventional canola. This was followed by no difference in yields for 2004, 2005, 2008, and 2010, and increases in yields of 4% for 2006 and 2007, 1.67% for 2009, 1.6% for 2011, 1.5% for 2012, and 3.1% for 2013. Also, according to the CBAN (2015), from 1996 to 2014 there was an average yield increase of 2.4% for herbicide-tolerant canola compared to conventional canola. Lastly, aggregate data for GM and conventional canola following the adoption of GM canola demonstrated an average increase in yields from 1996 to 2015 of 2% (see Figure 6.13).

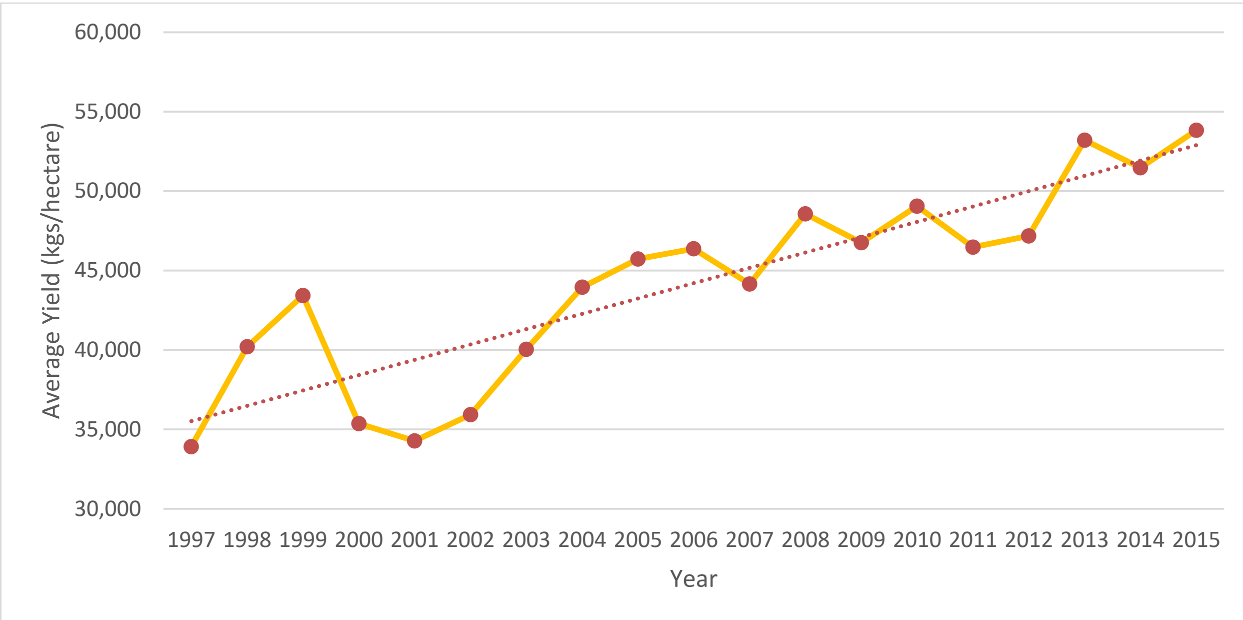
Figure 6.13: Average Canola Yield in Kilograms per Hectare from 1996 to 2015



Source: Statistics Canada, 2015b

The five farmers that adopted insect-resistant corn reported a general increase in yields compared to conventional corn. These results are consistent with other studies (see, for example, Brookes and Barfoot, 2015; CBAN, 2015; Hutchinson et al., 2010; Johnson and Strom, 2008; Saha et al., 2014). According to Brookes and Barfoot (2015), from 1996 to 2013 there was an average yield increase of 7% for insect-resistant corn (resistant to corn boring pests) and an average yield increase of 5% for insect-resistant corn (resistant to corn rootworm). Also, according to the CBAN (2015), from 1997 to 2014 there was an average yield increase of 1.9% for insect-resistant corn compared to conventional corn. Lastly, aggregate data for GM and conventional corn following the adoption of GM corn demonstrated an average increase in yields from 1997 to 2015 of 3.1% (see Figure 6.14).

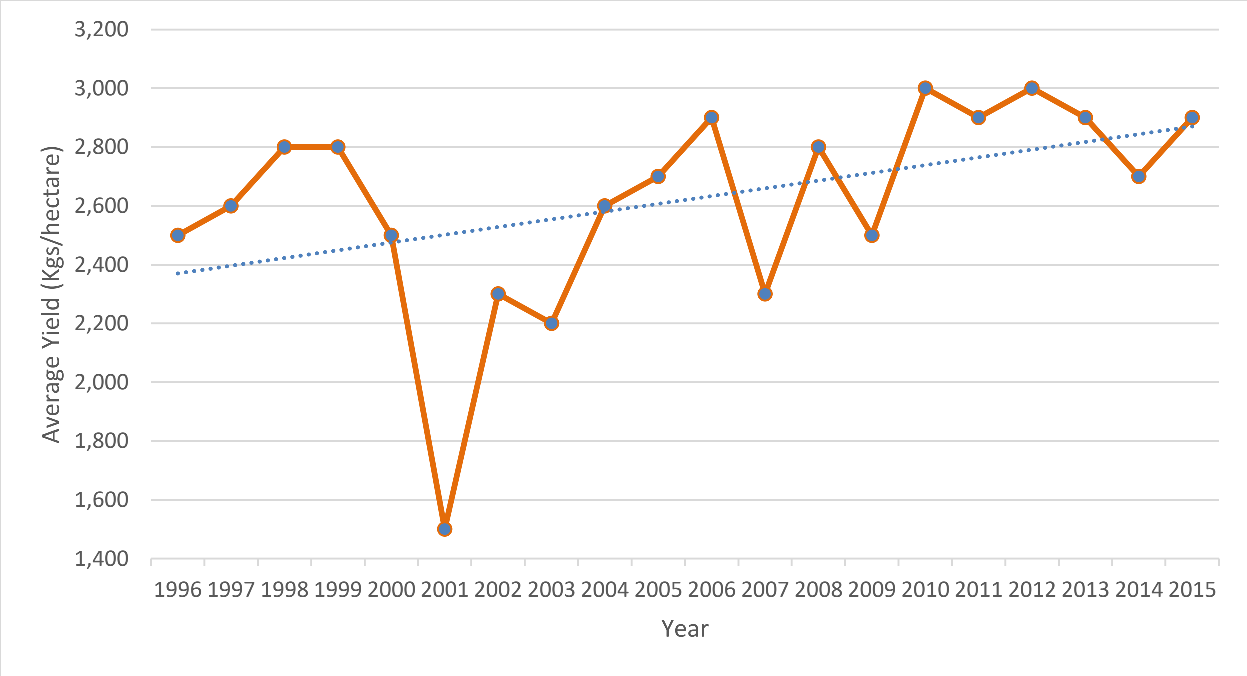
Figure 6.14: Average Corn Yield in Kilograms per Hectare from 1997 to 2015



Source: Statistics Canada, 2015b

The five farmers that adopted herbicide-tolerant soybean reported no increase in yields in the initial years of production using first generation seeds followed by an increase in yields in the later years of production using second generation seeds compared to conventional soybean. These results are consistent with other studies (see, for example, Brookes and Barfoot, 2015; CBAN, 2015; Saha et al., 2014). According to Brookes and Barfoot (2015), from 1996-2008 there was no yield increase for first generation herbicide-tolerant soybean compared to conventional soybean. This was followed by increases in yields for second generation herbicide-tolerant soybean of 5% for 2009 and 2010, 10.4% for 2011, 11.2% for 2012, and 11% for 2013. Also, according to the CBAN (2015), from 1996 to 2014 there was an average yield increase of 0.8% for herbicide-tolerant soybean compared to conventional soybean. Lastly, aggregate data for GM and conventional soybean following the adoption of GM soybean demonstrated an average increase in yields from 1996 to 2015 of 0.8% (see Figure 6.15).

Figure 6.15: Average Soybean Yield in Kilograms per Hectare from 1996 to 2015



Source: Statistics Canada, 2015b

While there has been an increase in yields following the production of GM corn, canola, and soybean, increase in yields of the same crops also occurred prior to the introduction of GM traits. For example, according to Statistics Canada (2015b), the annual average increase in yields of conventional canola, corn, and soybean from 1966 to 1995 were 1.3%, 0.9%, and 1.4% respectively. Also, the annual average increase in yields of other major conventional crops in Canada, such as wheat, barley, and oats, from 1996 to 2015 were 1%, 0.4%, and 1.3% respectively.

The yield traits of a plant are determined by the pre-existing genetic characteristics of the conventional variety into which the genetic sequence is inserted.

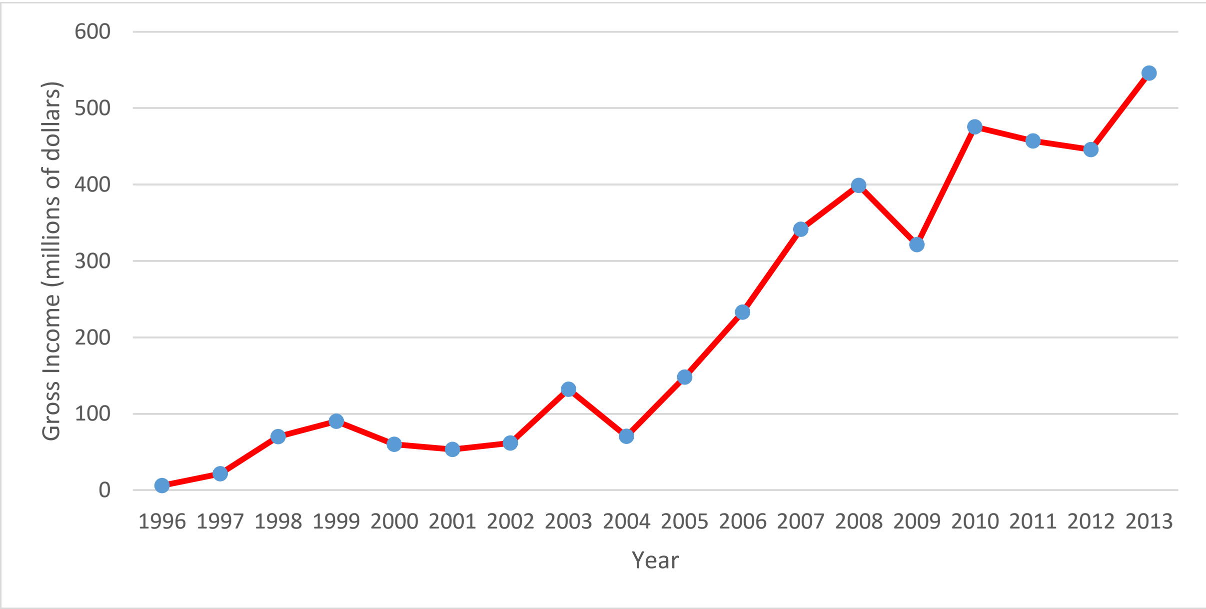
GM crops are high-yielding conventional crops that have genetic sequences inserted to predominantly tolerate herbicides or resist insects. GM crops are engineered to decrease crop losses and may or may not result in higher yields. In some cases, yield may decrease if the varieties used to carry the herbicide-tolerant or insect-resistant genes are not the highest yielding cultivars. However, by protecting the plant from certain pests, GM crops can prevent yield losses compared with conventional varieties, especially when infestation of susceptible pests occurs. This effect is particularly important in Bt crops. For example, before the commercial introduction of Bt corn in 1996, the European corn borer was only partially controlled using chemical insecticides. The economics of chemical use were not always favorable and timely application was difficult, so farmers often accepted yield losses of 3% to 6% per one corn borer per plant depending on the stage of plant development rather than incur the expense (Fernandez-Cornejo and McBride, 2002). Increases in yields as well as yearly fluctuations are attributed to many factors including: improvements in conventional breeding, geographical location, environmental changes, fertilizer and pesticide use, agronomic practices, farm machinery, and farm management (Veeman and Gray, 2009).

6.4.3 GM Crops and Farm Level Income

The 19 Canadian farmers that participated in this research reported a general increase in gross farm income following the adoption of GM canola, corn, and soybean. This is consistent with other studies that examine farm level impact (see, for example, Beckie et al., 2006; Beckie et al., 2011; Brookes and Barfoot, 2015). For example, according to

Brookes and Barfoot (2015), national gross income for Canadian farmers that planted herbicide-tolerant canola increased from $6 million in 1996 to a peak of $546 million in 2013 (see Figure 6.16).

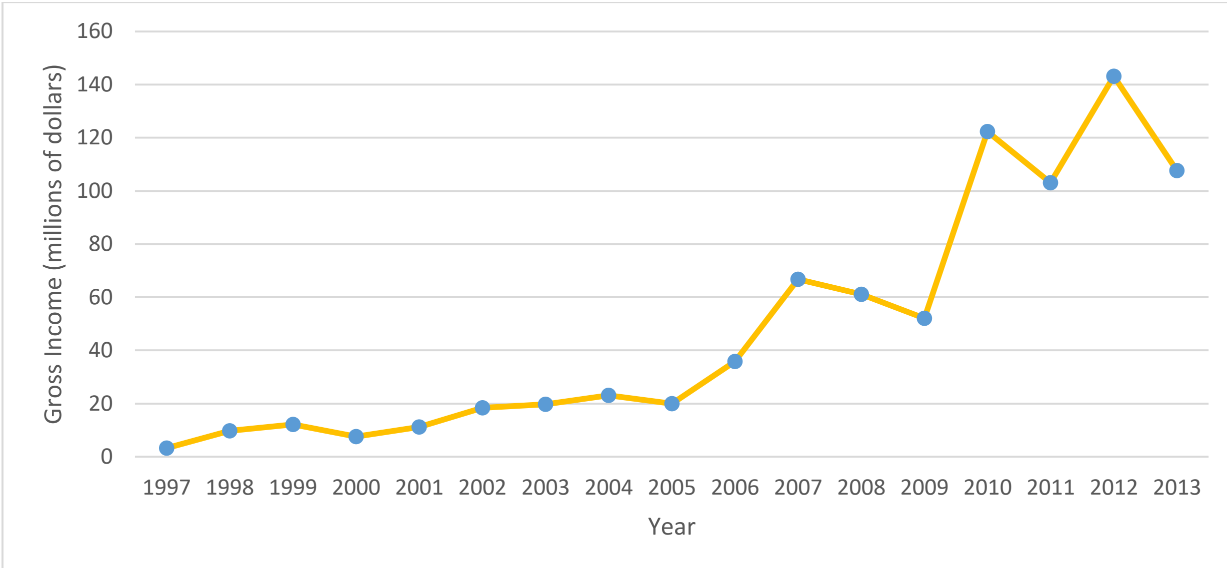
Figure 6.16: Gross Farm Income for Canadian GM Canola from 1996 to 2013



Source: Brookes and Barfoot, 2015b

Also, national gross income for Canadian farmers that planted insect-resistant corn increased from $3.2 million in 1997 to a peak of $143 million in 2012 and down to $107 million in 2013 (see Figure 6.17).

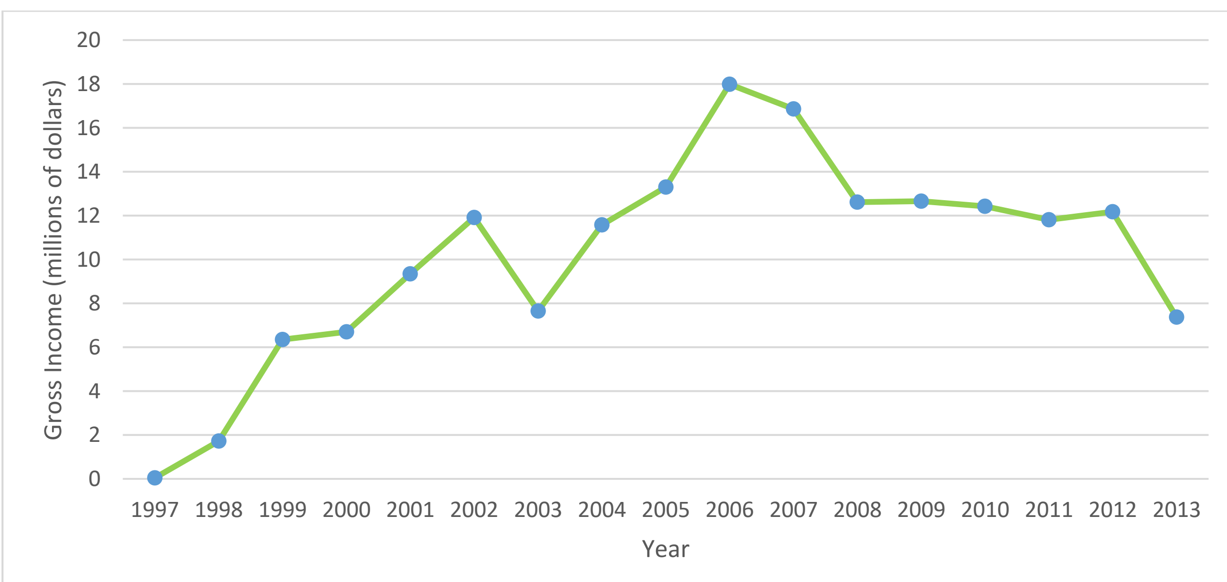
Figure 6.17: Gross Farm Income for Canadian GM Corn from 1997 to 2013



Source: Brookes and Barfoot, 2015

Lastly, national gross income for Canadian farmers that planted herbicide-tolerant soybean increased from $41,000 in 1997 to a peak in 2006 of $18 million and down to $7 million in 2013 (see Figure 6.18).

Figure 6.18: Gross Farm Income for Canadian GM Soybean from 1997 to 2013



Source: Brookes and Barfoot, 2015

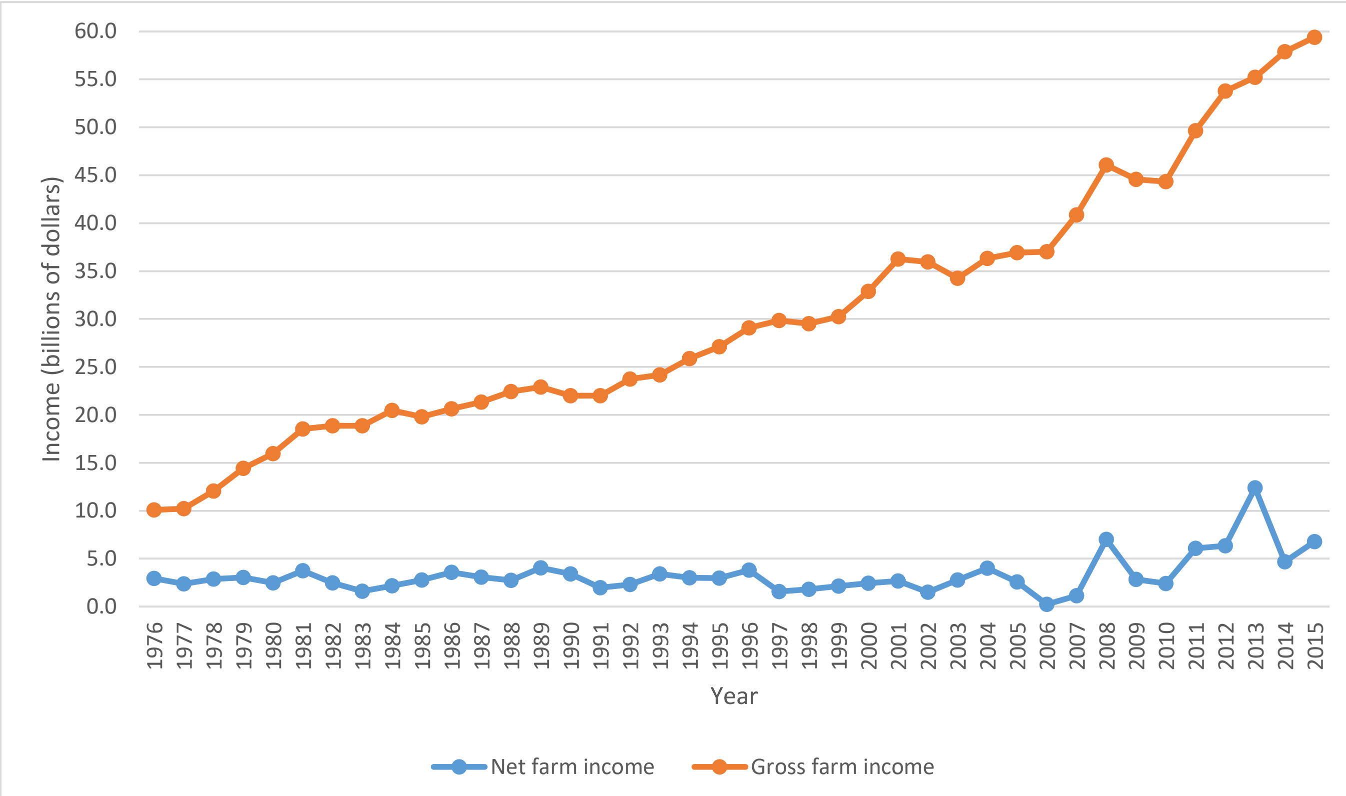
Despite a general increase in gross farm income, farmers also reported a general stagnation in net farm income prior to and following the adoption of GM canola, corn, and soybean. Two GM crop farmers in interviews commented about these factors.

> "I mean we are bringing in more money overall, but when you look at what's left over I don't think I am making much more than my father used to. Perhaps I might even be making less, even though I have a lot of advantages with all the new equipment available to farmers these days; but the income has not changed much at all before or after we started using GM" (Independent Farmer 2).

> "Farming has changed a lot over the years, and I really don't think it has been easy for any generation of farmers. I think overall though, my father worked a lot harder than we do these days mostly because of the new equipment available to those of us farming now, but you know the incomes that we earn have not changed much. I mean it goes up and down depending on the year but it has been basically the same" (Independent Farmer 3).

The sentiment expressed by these farmers is consistent with Canadian farm income data. Although Statistics Canada does not disaggregate data on farm income according to crop type, available data confirms a stagnant total net farm income from 1976 to 2015 despite an increase in gross income or farm cash receipts (See Figure 6.19).

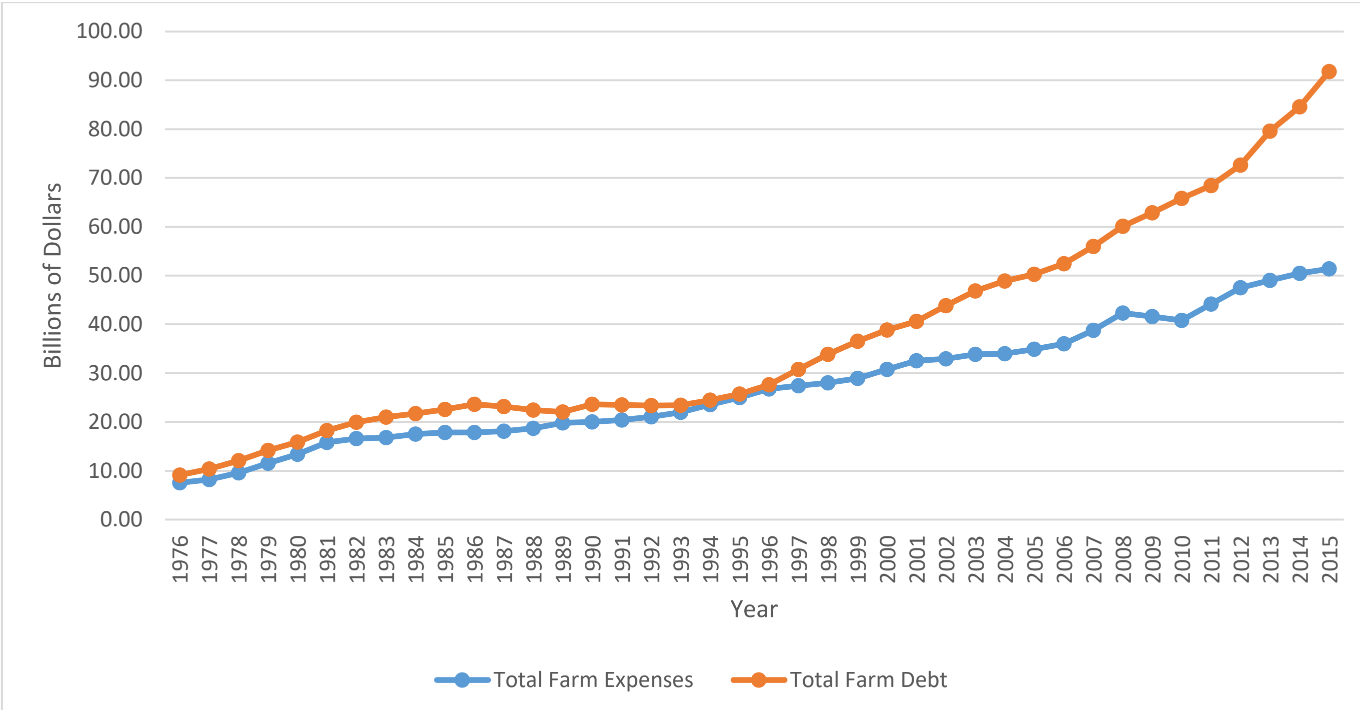
Figure 6.19: Annual Average Farm Income from 1976 to 2015



Notes and sources: total net farm income measures the financial flows, both monetary (cash income) and non-monetary (depreciation and income-in-kind), and stock changes of farm businesses. Total net income values agriculture economic production during the year that the agricultural goods were produced. It represents the return to owner's equity, unpaid labour, management, and risk, (AAFC and Statistics Canada, 2000; Statistics Canada, 2016b). Also, total farm cash receipts or gross farm income include revenues from the sale of agricultural commodities, program payments from government agencies, and payments from private crop and livestock insurance programs. Receipts are recorded in the calendar year when the money is paid to the farmer, (AAFC and Statistics Canada, 2000; Statistics Canada, 2016b).

Moreover, while net farm income has remained stagnant, farm expenses and farm debt have increased (see Figure 6.20).

Figure 6.20: Total Canadian Farm Expenses and Debt from 1976 to 2015



Sources: Statistics Canada, 2016a, 2016d

Two GM crop farmers in interviews commented about these factors.

> The cost of running a farm is going up. I mean, sure, the cost of the GM products like seeds and chemicals has gone through the roof but so have other costs. I'm looking at my numbers here for the last few years, and quite seriously everything is costing me more: taxes, wages, machinery fuel, repairs, insurance, and on and on (Independent Farmer 4).

> One of the things that has changed though, is that farmers borrow a lot more money than they used to, which is becoming a big part of running a farm these days. Cost of leasing equipment is high, also GM products are very expensive. My father had very little debt, but almost everyone I know in farming these days seems to be getting more and more in debt (Independent Farmer 5).

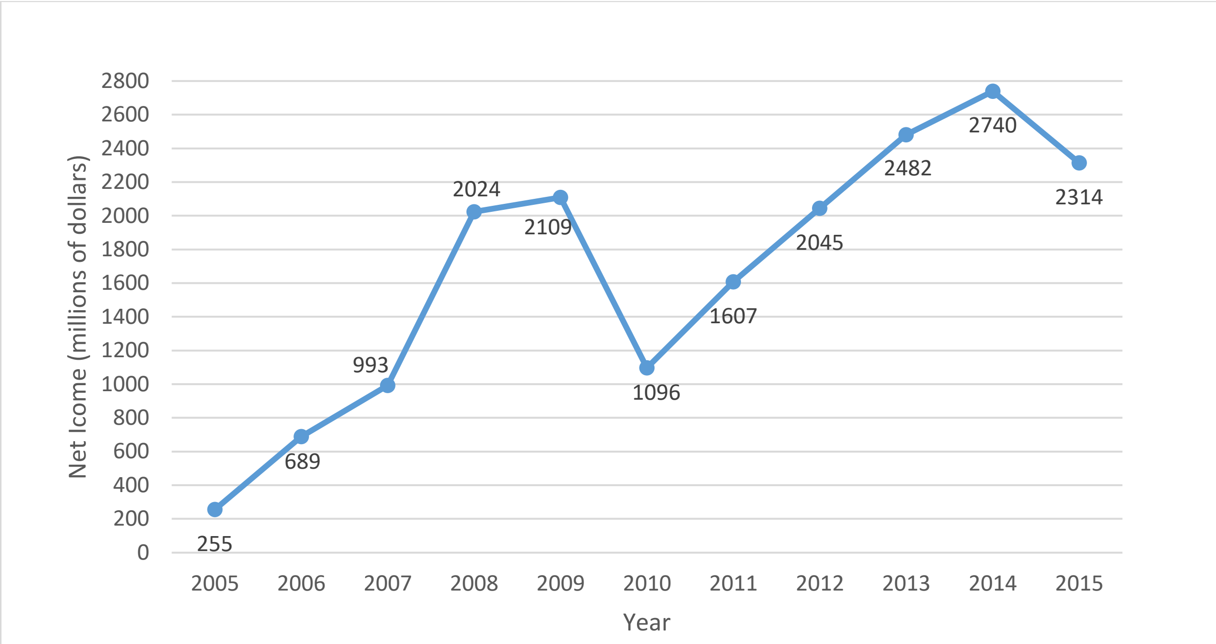
The more recent exponential rise in farm debt has been fueled by higher farm expenses, low farm operator income, the availability of credit at low interest rates, and rising farm land values. According to the Farm Credit Corporation (FCC), Canadian farm land values have risen dramatically since 2008. Average values of land and buildings range from $881 per acre in Saskatchewan to $8,417 per acre in Ontario, up from $453 per acre in Saskatchewan and $4,593 per acre in Ontario. The weighted-average price of Canadian farmland and buildings was $2,227 in 2013 compared to $1,394 in 2008. In 2013, the average value of Canadian farm land increased 22.1%, the highest national increase since the FCC began reporting on farm land values in 1985 (FCC, 2014). The federal government of Canada has been supportive of farmers borrowing from the FCC. This allows cash-strapped farmers easier access to operating loans particularly when farm land can be used as collateral. The FCC benefits from, on the one hand, rising farm land values that allow for larger loans, and on the other hand, the cost-price squeeze that induces farmers to borrow to increase production in hope that higher volume will compensate for narrower margins. The outcome has been an increase in the total dollars lent out to farmers and the average annual amount of interest farmers are paying (NFU, 2010).

In addition to loans from the FCC, are loans from supply companies and private investors. Supply companies are increasingly financing farmers' input purchases such as seeds, chemicals, and fertilizers. Farmers turn to supply companies to access credit for working capital. The credit is tied to the purchase of inputs and both the credit and the purchased inputs are tied to crop delivery contracts back to the supply company. Through this arrangement, the supply company not only profits from selling farming inputs, but also from the interest on the credit to farmers and the crops that the farmers produce. Also, private investors 'participate' with the farmer by providing operating capital and taking part of the crop at the end of the year. This type of financing is a vehicle to sell investors what amounts to a financial derivative based on crop prices and a virtually unregulated type of private high-risk financing that is marketed to farmers as a source of money for inputs and other operational purchases. Farmers lose autonomy when the loan payments and loan conditions constrain choices about how the farm is run and how willing the farmer is to try different production methods that incur financial risk. For example, farmers who access credit from a supply company must purchase inputs from the same company and not necessarily where the inputs are cheapest. Also, in cases where farmers want to make a transition from, for example, conventional to organic agriculture or from one crop to another, such transitions are difficult because high loan payments prevents farmers from costly transitions and nervous investors may not invest in farmers who may want to change direction without assurance of quick success (NFU, 2010).

The impact of adopting GM crops on farm income is attributed to additional factors such as: global and domestic commodity prices, currency exchange fluctuations, and trade decisions; the profitability of a crop in terms of how much any benefits outweigh the cost of inputs such as seeds, pesticides, fertilizers, fuel, and land; farm management and agronomic practices; and geographical location and environmental attributes affect profitability directly through increased fertility and indirectly through its influence on pests.

Lastly, despite stagnant net farm income, increasing farm expenses, and increasing farm debt, the net income of multinational GM seed and agrochemical corporations continue to rise at unprecedented rates. For example, Monsanto's average annual net income from 2005 to 2015 has increased a remarkable 80.7% from a net income of US$255 million in 2006 to US$2.3 billion in 2015 (see Figure 6.21).

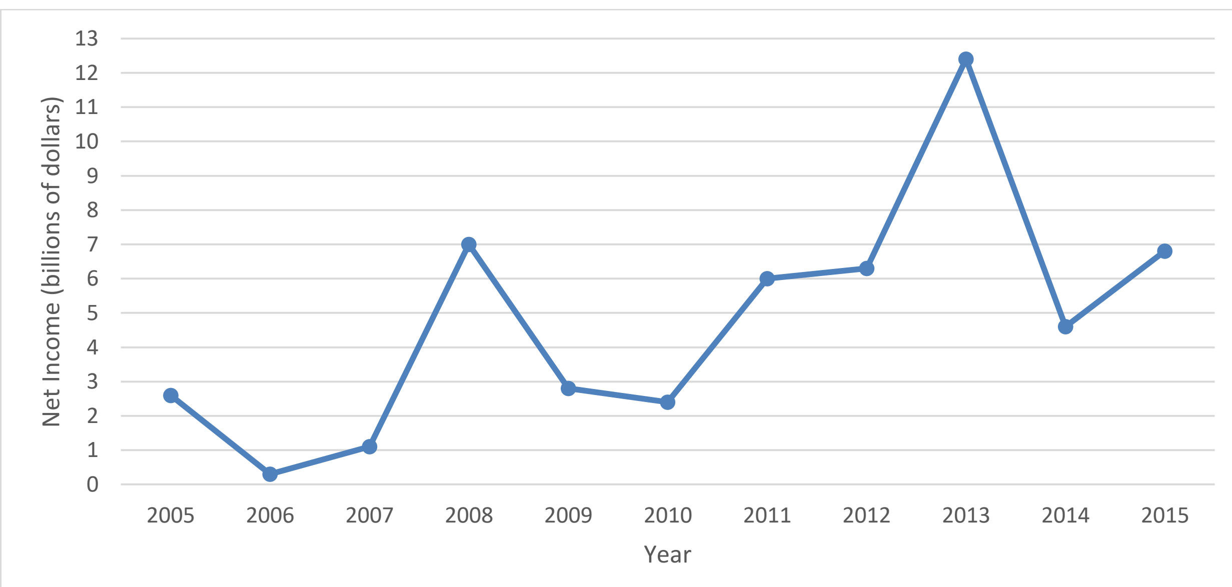
Figure 6.21: Monsanto Net Income from 2005 to 2015



Sources: Monsanto, 2007, 2010, 2013, 2016b

During the same period, average annual net farm income increased 16.2% from $2.6 billion in 2005 to $6.8 billion in 2015 (see Figure 6.22).

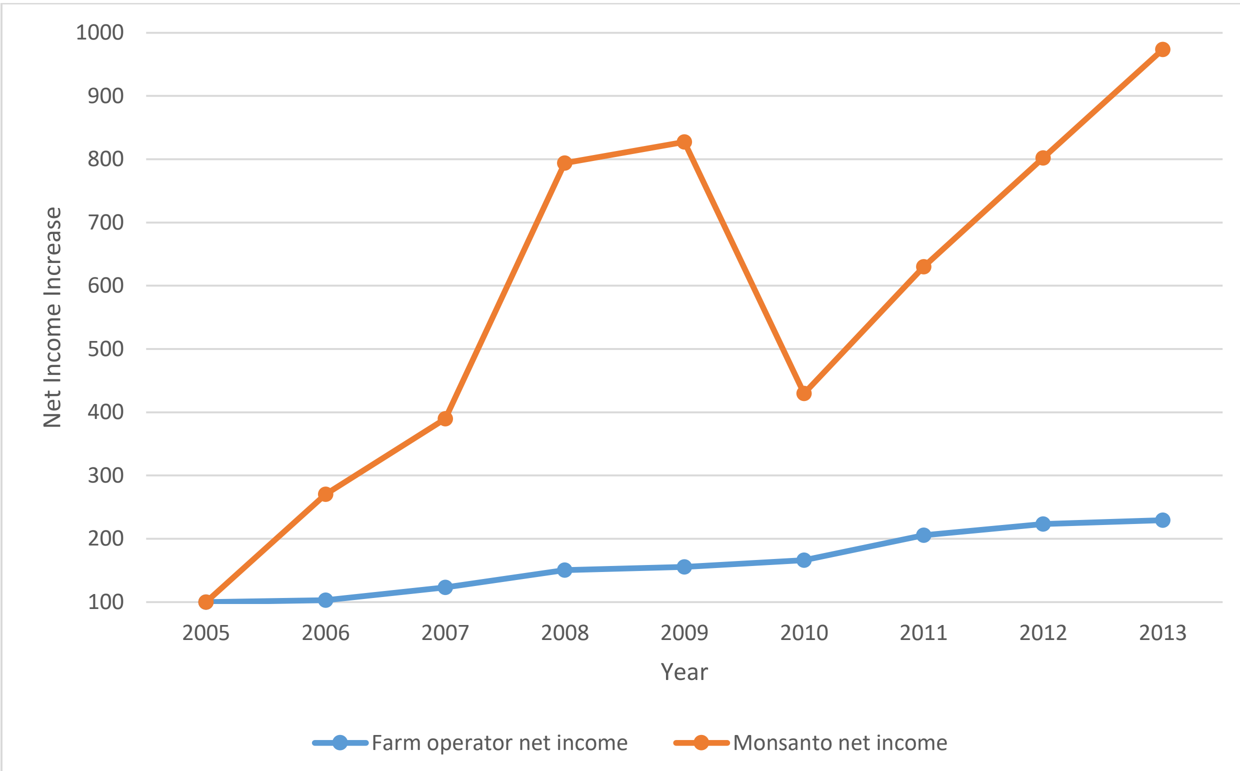
Figure 6.22: Farmer Net Income from 2005 to 2015



Source: Statistics Canada, 2016b

An index comparing the net income of Monsanto to that of farm operators in Canada using the 2005 net incomes as a base demonstrates the dramatic increase in the net income of Monsanto compared to that of farm operators (see Figure 6.23).

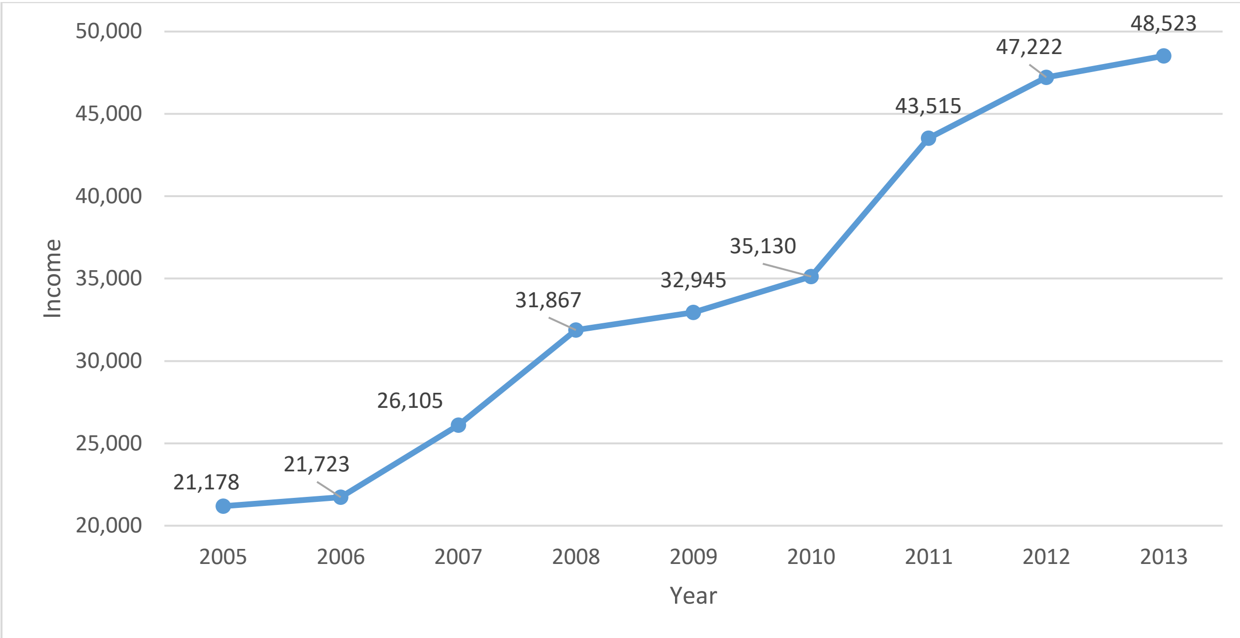
Figure 6.23: Net Income Index of Monsanto and Farm Operators



Sources: Monsanto, 2007, 2010, 2013, 2016b; Statistics Canada, 2016b

The average annual income per farm operator in 2005 was $21,178 which increased to $48,523 (most recent year that data is available) (see Figure 6.24). To put this in perspective, Monsanto's (2014a) and DuPont's (2014a) net income in 2013 exceeded the net income of approximately 205,000 farmers in Canada.

Figure 6.24: Annual Income per Farm Operator from 2005 to 2013



Source: Statistics Canada, 2016e

Multinational agribusiness corporations, such as Monsanto, use their increased market share to expand their reach through mergers and acquisitions, resulting in fewer and larger companies involved in selling inputs to farmers. The imbalance of profitability between multinational agribusiness corporations and farmers is severe as corporations pursue 'competitiveness' with other companies on the world stage by taming governments and using their market power to enforce conditions on producers that ensure continued increases in corporate profitability.

6.5 Conclusion

Agricultural restructuring has brought significant changes to Canadian farming. This has included an increase in off-farm mechanical (e.g., machinery) and biological (e.g., GM seeds and associated agrochemicals) inputs, farm production that is increasingly focused on fewer and larger farms in the most productive regions, large capital-intensive farms that focus on fewer farm products as resources are devoted to those items giving the best comparative advantage, a decrease in farm subsidies, government agricultural policy shifts that favour the private sector, and unfavourable environmental and market conditions. Among the purported solutions to these perplexing issues has been intense innovation in the agricultural sector, funded by the Government of Canada and multinational corporations, aimed at economic growth and the expansion of value accumulation in an era of competitive innovation in high-technology industries. This is manifested in the rise and consolidation of a handful of multinational GM seed and agrochemical corporations, vigorous marketing and government regulatory approval of GM products, the appropriation of germplasm, rapid expansion of IP rights, and the high adoption and production of GM crops. Farmers are increasingly dependent on commodified (GM) seeds, which have been rapidly converted from public goods and means of production controlled by direct producers, into commodities controlled by multinational corporations, sold and purchased in transnational markets. The serious consequences for farmers have included a significant increase in the cost of inputs such as GM seeds and associated agrochemicals relative to other operational costs; GM seeds that are less adapted to their regions and less resilient to environmental change; fewer choices for farmers as conventional seeds are phased out; and less farmer autonomy due to stringent contracts that prevent farmers from selecting, saving, exchanging, selling, and reusing seeds. Although there has been a rise in yields and gross farm income as a result of adopting GM crops, net farm income has remained stagnant due to an increase in farm expenses and debt while the net income of leading

GM seed and agrochemical corporations has increased sharply as farmers become more dependent on commodified off-farm inputs that are increasingly controlled by multinational agribusiness corporations.

Moving away from positivist and empiricist approaches to understanding the economic effects of the adoption and production of GM crops, my analysis provides a different perspective by highlighting the dynamics of intra-class competition in capitalist society and the ensuing drive toward technological innovation in the agricultural sector. Agricultural biotechnology innovations have been predominantly driven by the profit imperative as multinational agribusiness corporations compete with each other in order to produce new technologies such as GM seeds and associated agrochemicals for sale in the agricultural sector. This is illustrated by reviewing the principal technologies on the market today: herbicide resistant crops, such as Monsanto's Roundup Ready seeds, which are tolerant to Monsanto's herbicide Roundup, and Bt (Bacillus thuringiensis) crops, which are engineered to produce their own insecticide. In the first instance, the goal is to win a greater herbicide market share for a proprietary product, and in the second, to boost seed sales at the cost of damaging the usefulness of a naturally occurring pest management bacterium (the Bacillus thuringiensis based microbial insecticide) relied upon by many farmers for centuries as a powerful alternative to insecticides (Altieri and Rosset, 1999). These technologies respond to the imperative by GM seed corporations to intensify farmers' dependence on seeds protected by IP rights, which conflict directly with the rights of farmers to reproduce, share or store seeds (Kloppenburg, 2004). Whenever possible corporations require farmers to buy a company's brand of inputs and forbid farmers from keeping or selling seeds. By controlling germplasm from seed to sale, and by forcing farmers to pay for seeds and related agrochemicals, companies are determined to extract the greatest profits from their investment. Also, agricultural restructuring in the Canadian context more specifically and the global context more generally has resulted in the ongoing stagnant net farm income for millions of farmers. Accordingly, farmers have sought various technologies, including GM seeds and associated agrochemicals that promise to deliver enhanced productivity and efficiency gains in order to increase their net income. The outcome, however, has been the continued stagnation of net farm income while the net income of multinational GM seed and agrochemical corporations continue to rise. These processes constitute a major driving force behind the restructuring and transformation of the Canadian agriculture and agro-food system.

Chapter Seven

Conclusion

7.1 Introduction

The development of agricultural biotechnology is a function of capitalist development where the interests of individual and interrelated capitals in the biotechnology sector coalesce around agricultural and food production and the re-orientation of production systems. Although many exceptional innovations in the agricultural biotechnology sector have emerged, these cannot be taken as simply the outcome of scientific and technological practices, but the result of social agents exercising political and economic influence in the general parameters of capitalist development and the need for particular capitals to enhance their potential for increasing (monopolistic) profit and to strengthen their market position in an era of competitive innovation in high-technology industries.

7.2 Research Findings

The history and geography of the development of agricultural biotechnology in Canada may be traced to many important events beginning with the technological innovations that occurred in the rapeseed oil industry. During the Second World War, blocked oil imports led policy-makers to perceive Canada's dependence on foreign oil for industrial and dietary purposes as a national weakness. This prompted the development of the Canadian rapeseed oil industry (Busch and Juska, 1997). During the following three decades, significant investment by government agencies and innovations by public sector scientists in germplasm and other technologies transformed industrial rapeseed oil into an edible oil with superior nutritional properties trademarked as canola (CCC, 2014).

Following this period, important developments occurred in the 1980s inside the canola industry and outside of it. In 1980 the Rapeseed Association of Canada changed its name to the CCC as well as its focus from improving the nutritional properties of canola to improving the production characteristics and marketing of the product. Accordingly, private companies began to take interest in the Canadian canola industry and increased their contribution to the CCC's R&D efforts. This resulted in greater emphasis on the requirements of agribusiness corporations, especially those associated with agricultural inputs and processing. The outcome was a tightly coordinated R&D program between the private industry, public institutions, and the CCC (Gray et al., 2001).

In addition, the high debt, drought, and trade wars of the 1980s brought significant structural changes to Canadian farming. Farm numbers in Canada continued a 50-year decline while farm annual revenue and farm size increased. The Government of Canada responded to the financial difficulties facing many farmers through various subsidy programs (Dakers and Forge, 2000). Also, AAFC changed its focus in the mid-1980s from improving and maintaining productivity in farming to fostering competitiveness and economic growth. This resulted in a shift from practices that benefit Canadian farmers in favour of contracts and partnerships that meet private-sector needs (Moore, 2002).

Lastly, GM crops were created in the early 1980s by four groups of researchers working independently at Monsanto and Washington University in St. Louis, Missouri; University of Wisconsin in Madison, Wisconsin; and the University of Groningen in Ghent, Belgium (Werhane et al., 2004). Throughout the 1980s, there was a surge of investment in the development of agricultural biotechnology, initially by start-up companies financed by venture capital followed by multinational corporations. The decision by the US Patents and Trademarks Office to grant patents for whole plants in 1985, and the introduction of canola hybrid technologies and the first hybrid variety in 1989, prompted the Government of Canada to pass the Plant Breeders' Rights (PBR) act in 1990 (CFIA, 2015).

Several developments occurred in the 1990s which further consolidated the biotechnology industry in Canada. The PBR strengthened private control over IP in the seed and breeding business. This resulted in significantly greater use of contracts, often involving a web of relationships that link research units with seed companies, other input providers, farming communities, processors, and marketers. The private growth in the seed and breeding business was increasingly encouraged by the Canadian federal and provincial governments. Public sector research agencies refocused their efforts to complement private sector interests (Gray et al., 2001).

Moreover, a concerted campaign based on aggressive corporate mergers and acquisitions as well as partnerships among the largest multinational corporations in agricultural biotechnology was taking place with Monsanto emerging as the largest player in the industry (Peekhaus, 2013). Monsanto received regulatory approval from Health Canada to market glyphosate tolerant canola for food use in 1994, glyphosate tolerant soybean in 1996, and insect resistant corn in 1997 (Health Canada, 2015). With the R&D structure and IP laws well established, the Canadian Biotechnology Strategy Task Force (CBS) was inaugurated in 1997. The CBS consulted with provincial officials, industry, non-government organizations (NGOs), scientists, academics, and other relevant stakeholders about the visions, goals, and principles of renewed national biotechnology strategy as well as its impact on biotechnology R&D. The CBS's broader range of issues included social, ethical, health, economic, environmental, and regulation; however, it was explicitly clear that commercial interests continued to play an important role. The formation of the CBS was followed by the establishment of the CBAC in 1999. The CBAC identified five research areas: the regulation of GM foods, IP related issues in biotechnology, novel uses of biotechnology such as stem cells, the integration of ethical and social issues into biotechnology, and the consequences for privacy that emerges surrounding biotechnology (CBAC, 2006).

Heading into the 2000s, the Government of Canada had clearly positioned itself as a world leader in biotechnology R&D and commercialization. The Canadian Crop Genomic Initiative developed Canadian GM crops, such as corn, soybean, canola and wheat, to improve disease and insect resistance, cold and drought tolerance, and yield and quality attributes (Government of Canada, 2003). Also, further consolidation had been occurring among GM seed and agrochemical corporations. According to Peekhaus (2013, 42-44), the world's top 11 GM seed companies: Monsanto (US), DuPont (US), Syngenta (Switzerland), Groupe Limagrain (France), Land O'Lakes (US), KWS SAAT SE (Germany), Bayer (Germany), Dow (US), Sakata (Japan), DLF-Trifolium (Denmark), and Takii (Japan), accounted for approximately 37% of the global proprietary seed market in 1996, which increased to 55% in 2007, and 62% in 2009. In 2009, the top three companies (Monsanto, DuPont, and Syngenta) controlled 45% of the global proprietary seed market. Monsanto controlled 23% of the global proprietary seed market, and an estimated 87% of the total land area planted with GM seeds was planted with Monsanto products either directly or indirectly through licences to other companies. As of 2013, the world's top three seed companies, Monsanto, DuPont, and Syngenta accounted for 26%, 21%, and 8% respectively or 55% collectively of the global proprietary seed market, while the top three agrochemical companies, Syngenta, Bayer, and BASF accounted for 20%, 18%, and 13% respectively or 51% collectively of the global agrochemical market. Collectively, the top six companies: Monsanto, DuPont, Syngenta, Bayer, Dow, and BASF accounted for 65% of the global proprietary seed market, and 75% of the global agrochemical market with sales exceeding $65 billion per annum (ETC Group, 2015).

In Canada, GM canola is grown by 43,000 farmers, accounting for more than 98% of all canola, mostly in the western provinces of Alberta, Saskatchewan, and Manitoba. Annually, the GM canola industry contributes $19.3 billion to the economy, including more than 249,000 Canadian jobs and $12.5 billion in wages (CCC, 2016). GM corn plantings have been steadily increasing, accounting for 83% of all corn planted in Canada. Quebec and Ontario are the primary corn-growing regions, accounting for 90% of total Canadian corn areas. GM soybean accounted for more than 90% of total soybean acreage in 2007. Ontario and Quebec accounted for approximately 69% of total soybean acreage, while Manitoba's share has risen from 8% in 2007 to 23% in 2013 (Dessureault and Lepescu, 2014). GM sugar beet has been planted in Canada since 2008. Production is concentrated in Taber, Alberta where Canada's only sugar beet processing plant is located. In 2010, 96% of the sugar beet crop (approximately 13,000 ha) was GM sugar beet (Evans and Lupescu, 2012).

Despite the high rate of adoption and production of GM crops, not only in Canada but also globally, the genetic modification of agriculture has resulted in dramatic conflicts. By the late 1990s, countries in Western Europe outright rejected the adoption of GM crops, and opposition emerged in many regions around the world (Herring, 2007). Moreover, in Canada there has been widespread disagreement among scientists, activists, regulators, and the general public about how to understand genetic modification in agriculture and what the possible positive or negative outcomes may be from the production of GM crops. Variously positioned social movement groups in a wide diversity of geographical locations have emphasized different concerns including the moral imperatives of 'playing god' or patenting life forms, the safety of foods derived from genetic modification, the ecological impacts of introducing novel plants into the environment, the loss of the ability of farmers to save seeds, 'biopiracy' through patent laws, and the control that multinational corporations are gaining over agriculture, science, and regulatory apparatuses (Eaton, 2013). Despite this extremely wide-ranging set of issues, public and academic debate tends to coalesce around either pro- or anti-GM crops discourses. Such controversies have given rise to a globally contentious politics and unprecedented policy dilemmas (Herring, 2007).

The emergence of agricultural biotechnology in the Canadian context is not only the result of the efforts of individual capitals, but also those of the Canadian state. This raises issues about the relationship of the state to, on the one hand, capitalist social relations, and on the other hand, science and technology. By virtue of its insertion into the structure of capitalist social relations, the state must promote value accumulation and reproduce the capitalist system. The social relations of capitalism require a regularized set of behaviours as well as the assurance of particular interaction between classes. The state continues to be the arbiter of that interaction and an entity which enforces an environment that is most amenable for the continuation of capitalist development. However, the particular form (e.g., policies that the state implements) the state takes and the outcomes are contingent on specific historical, geographical, and material conditions prevalent under capitalist social relations. The Government of Canada's agricultural biotechnology policy, regulation, and funding regimes demonstrate the degree to which the economic is embedded in political structures of power as well as the reflexive nature of those political forms that depend in part on the economy for their continued existence.

Regarding the relationship of the state to science and technology, the Canadian state has been a critical non-economic actor in the drive toward agricultural biotechnology R&D aimed at commodity production. Interestingly, this is contrary to the neo-liberal rhetoric advanced since the 1980s about the state withdrawing from active participation in the economic markets and political regulation and control of advanced industrial capital (Harvey, 2005). In fact, the Government of Canada's agricultural biotechnology science and technology policy implementation, regulatory practices, and funding structures have become part of the general and external guarantees of the social conditions of production directed toward specific capitals as well as the sector as a whole. This demonstrates that in order for the state to ensure value accumulation and the reproduction of the capitalist system it must provide certain tangible, advantageous preconditions. The pursuit of growth policies necessitates an infrastructure that requires significant capital outlays which cannot be realized by individual capitals. Public policy is utilized to transfer social surplus value into particular sectors that not only give extra incentives to develop science and technology, but minimize the associated risks of venturing into such avenues (Hirsch, 1978; Loeppky, 2005). This is orchestrated in different ways, such as funding projects, tax relief incentives, infrastructure development, and so on. By accepting and promoting capitalist control over the development of biotechnology R&D, the Canadian state has been compelled to operate in ways that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

The state's involvement in science and technology represents a field in which particular groups can gain ascendancy while negotiating for the most advantageous policy. Indeed, the state can, against the will of many capitals, force the procurement of scientific and technological advance. Accordingly, state science and technology policy cannot be understood as the smooth reaction of the requirements of (re)production (Hirsch, 1978), but by the partial interests of civil society, individual capitals, and the general reproduction demands of capital as a whole. The theoretical understanding of the state in relation to technology must, like all state functions, be mediated through the course and results of political (class) struggle. In this sense, not only is the examination of state policy an examination of fundamental social relations, but the specific case of agricultural biotechnology in Canada offers an illustration of its contradictory tendencies. In the face of the separation between the political and the economic, the state's ostensible ‘neutral’ mobilization is systematically pressed into the service of partial interests within capital (Leoppky, 2005).

Since class struggle is inherent to capitalist relations of production, capital is compelled to engage in ideological strategies that provide the basis for accumulation in order to safeguard its existence. Any threat to the balance of power between classes that impedes capitalist accumulation is susceptible to such strategies. This may be illustrated by the efforts of the agricultural biotechnology industry with support from government scientific and financial capacities to engage in public relations campaigns, attacks on opponents, the maligning of unsympathetic scientific findings, intense lobbying, and the ability to disseminate information that is primarily sympathetic to the agricultural biotechnology sector. These strategies serve to constrain the discourse surrounding GM crops in ways that ensure the success of the industry for the greater goal of contributing to capitalist accumulation.

The pro-GM crops discourse raises the issue about the relationship between the development of science and technology and capitalist social relations of production. One of the arguments posited by the government and industry in the construction of the pro-GM crops discourse is the ostensibly ‘neutral’ development of science and technology under capitalist social relations of production and its corresponding specious and teleological claims about the putative capacity of science and technology to guarantee socio-economic progress. This perspective undermines the distinction between the development of science and technology in general and the development of science and technology under capitalist social relations of production, where the latter reflects the social relations under which it occurs. The appeal to science has provided government and industry a convenient strategy around which to circumscribe the social relations that underlie the pro-GM crops discourse. The development of science and (bio) technology is not a neutral affair. The conception of science and technology as asocial catalysts for progress independent of purposive human agency that benefits one group of people over another serves to obscure the social relations underlying the development of science and technology from the design and development stages of technological innovation. Such a conception not only relegates the social relations underlying new technologies to the instances of their application, but also casts their social effects on society as secondary and contingent. This suggests that scientists and technologists are the discoverers of laws and processes immanent in an exogenous natural realm. Progress is putatively rooted in the natural order of a world that triumphs over historical and social peculiarities. This discursive framing easily explains away social relations as unavoidable by-products of history's teleological march of progress that can be mitigated through the perspicacious applications of new technologies.

Moreover, the pro-GM crops discourse obscures some fundamental aspects of the role of the development of GM technology in agriculture. The development of science and technology in agriculture has allowed for the reduction in the cost of agricultural production by increasing labour productivity, decreasing the reproduction cost of labour-power, and increasing surplus production at the societal level. The combination of labour with GM technology results in more output (farmers plant GM crops and get a higher yield than if they plant conventional crops). The increased output or the higher yield must be understood not only in terms of its use-value (more food to be consumed), but also in terms of its surplus-value (a given input of labour in a given time produces more output). Moreover, GM seeds producers, such as Monsanto, are driven by the capitalist profit motive. Billions of dollars have been invested in the R&D of GM seeds. GM seeds producers, like any other commodity producers, rely on being the first to market so as to capture the largest market share and reap the gains from their investment. The immediate objective of GM seeds production is not human sustenance and well-being but increase in profits.

Lastly, the pro-GM crops discourse serves to, at best assuage and at worst sever, any meaningful debates and active participation of the public in determining the outcomes of the development of agricultural biotechnology. In particular, government and industry have been successful in narrowing the debate so that social, political, environmental, and ethical concerns (i.e., the so-called ‘non-scientific’ concerns) have been to a great degree elided. This has been accomplished by constructing a pro-GM crops discourse that, on the one hand, disarms any opposition to the development of agricultural biotechnology, and on the other hand, ensures the economic viability of the industry. Accordingly, such discursive struggles have material consequences for the development, adoption, and production of GM crops, seed saving and production, multinational corporations, Canadian farming, the public, and food production in general.

The Canadian farmers that participated in this research entered contracts with Monsanto to cultivate GM canola, soybean, and corn. The contract between the farmer and Monsanto significantly limits the farmer’s rights to the purchased seeds through a ‘no saved seed’ provision which prohibits farmers from saving seeds and/or reusing seeds from GM crops therefore requiring farmers to purchase GM seeds on an annual basis. The increasing demand for patented GM seeds has resulted in the deregistering and removal from the market of conventional varieties and the virtual cessation of public breeding of the major crops (corn, canola, and soybean) that have GM varieties in Canada. Also, since 2005 the federal government has shut down or decreased the funding to a number of public breeding institutions in Canada. As plant breeding increasingly shifted into the private sector, farmers payed more for GM seeds that are less adapted to their regions and less resilient to change (NFU, 2013). As conventional varieties are phased out, and because GM traits are bred into conventional varieties that have the best performance characteristics, buying GM seeds is often the only way that farmers can access modern, high-yielding varieties. This has diminished the choices available to farmers, while strengthening the control of major corporations (ETC Group, 2015). In addition, the profits generated from private breeding return to shareholders instead of farming communities and public breeding programs that initially developed the conventional crops which have genetic sequences. The most profound example in Canada is the development of rapeseed/canola (see Phillips and Khachatourians, 2001).

The passing of the Canadian Plant Breeders Rights legislation in 1990 provided legal control over seeds in the form of patents on genetic sequences and facilitated the use of end-point royalties. Patent protection over new genetic sequences is a legal mechanism that takes the ownership of seeds out of the hands of farmers. Although Canada does not permit the patenting of plants, new genetic sequences in plants can be patented, and patent-holders can stipulate the conditions under which the patented genetic material can be used. In practice, this means that patents allow the company that developed a GM trait to forbid farmers from saving and replanting seeds with that trait and public breeders from further selecting or developing it and require farmers to purchase GM seeds and associated products on an annual basis. Multinational GM seed companies spend billions of dollars on patents and patent lawyers, and on policing farmers (CBAN, 2015b).

Although there has been an increase in yields and gross farm income following the adoption of GM canola, corn, and soybean, there has also been a general. This has been fueled by higher farm expenses, low farm operator income, the availability of credit at low interest rates, and rising farm land values that provide farmers with secure collateral on debt. Simultaneously, the net income of multinational GM seed and agrochemical corporations continue to rise at unprecedented rates.

Multinational agribusiness corporations, such as Monsanto, use their increased market share to expand their reach through mergers and acquisitions, resulting in fewer and larger companies involved in selling inputs to farmers. The imbalance of profitability between multinational agribusiness corporations and farmers is severe as corporations pursue ‘competitiveness’ with other companies on the global stage by taming governments and using their market power to enforce conditions on producers that ensure continued increases in corporate profitability. This has resulted in an oligopolistic market structure in which the largest actors are able to increase prices, narrow genetic diversity in crops, and stagnate innovation. A related consequence of this consolidation is that the major corporations that control the global seed and agrochemical markets now also largely determine the priorities and future direction of agricultural research.

7.3 Contribution to the Academic Literature

My study of the development, adoption, and production of GM crops in the Canadian context brings into focus the social relations among a wide range of actors including: farmers, farmers' union, scientists, government bureaucrats and agencies, activists, civil society organizations, GM seed and agrochemical corporations, legislative bodies, and universities. The framework is grounded in a political-economic analysis that situates the intense scientific and technological advance in agricultural biotechnology in the context of the more general (albeit temporally and spatially uneven) tendency by advanced capitalism towards monopoly-protected technological innovation in its various forms (Mandel, 1978). I contribute to the academic literature that encompasses the political-economy, development, and civil society aspects of the development of agricultural biotechnology and the adoption and production of GM crops (see section *2.2.2 Agricultural Biotechnology*). I provide a novel perspective by focusing on the intra-class relations of competition as they relate to the technological aspect of the productive forces while abstracting from the capital-labour relation as a contributor to technical change. Competition impels capitalism towards perpetual revolutions in the productive forces. This occurs in different sectors of the capitalist economy, including the agricultural sector. Since farmers' income is remaining stagnant and in order for them to be competitive both nationally and internationally and produce crops at a low price, farmers seek new technologies such as GM seeds and associated agrochemicals (technological fix) since they cannot move their production sight to areas with lower production costs (spatial fix). Also, agribusiness corporations compete with each other in order to meet this demand by producing new technologies such as GM seeds and associated agrochemicals. Both of these commercial producers compete in their respective industries by either using a new technology (e.g., farmers producing GM crops) or producing a new technology (e.g., corporations producing GM seeds). The result is unequal class outcomes when we compare how farmers have fared relative to agribusiness corporations. In addition, I emphasize the capitalist character of the state. The capitalist state, which generally operates in the interests of capitalists, creates conditions for capitalist accumulation. The state does things which capitalists left to themselves are not able to do, for example, the procurement of costly R&D infrastructure that requires significant capital outlays. Lastly, I demonstrate the relationship between the discursive and the material in the construction of a pro-GM crops discourse and highlight the importance of civil society struggles, not only in opposition to the development of GM crops but also in support of the development of GM crops. Accordingly, the pro-GM crops discourse is employed to sustain and legitimate the sale and use of GM crops.[1]

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[1] While every effort was made to access statistical data on GM crops from a variety of sources, this has been challenging. Global data on the adoption and production of GM crops, including country specific information, has largely come from one source, the ISAAA, with little to no comprehensive data from any other sources. According to Peekhaus (2013), the accuracy of the ISAAA data has been questioned by NGOs and academics. For example, LobbyWatch claimed that in the 1998 *Global Status of Commercialized Biotech/GM Crops* "a figure of 12% was given by American farmers for GM soy yield improvements. However, a review of the results of over 8,200 university-based controlled varietal trials in 1998 showed an almost 7% average yield reduction in the case of the GM soy" (LobbyWatch, 2015). In the Canadian case, Peekhaus (2013) claimed that the 2011 *Global Status of Commercialized Biotech/GM Crops* reported that 10.4 million hectares of land were planted with GM crops, but according to Statistics Canada data approximately 9.2 million hectares of GM crops were planted in 2011. Moreover, tracking data on GM crops in Canada from a variety of sources has also been challenging. I contacted AAFC, the CFIA, and Statistics Canada and discovered that comprehensive disaggregate data according to conventional and GM crops are not available. Canadian agricultural statistics, for the most part, do not differentiate between conventional and GM crops and in cases where this is done the information is not comprehensive. For example, although GM corn and GM soybean have been cultivated since 1996 and 1997 respectively, initially in Ontario and Quebec and later in Manitoba, Statistics Canada began disaggregating statistics according to conventional and GM crops in 2006 for corn and soybean in Ontario and Quebec, but not in Manitoba. In the case of GM canola, the only comprehensive data comes from the CCC, while data on GM sugar beet is very limited (Peekhaus, 2013). In order to maintain consistency, I have drawn primarily on data from

7.4 Further Research

In this section I make three recommendations for further research. First, one of the most debated issues in the controversies surrounding GM crops pertains to whether or not or how to label GM food products. Food labels are an important source of information about the attributes of food that consumers can use in their decision-making processes, however, there are both economic and political implications involved in deciding what can and should be included on food labels. Various divergent perspectives have been advanced by academics (see, for example, Dieterle, 2016; Huffman, 2016; Huffman and McCluskey, 2014; Sorqvist et al., 2016; Zilberman et al., 2013), activists (CBAN, 2016b; Centre for Food Safety, 2016; Just Label It Campaign, 2016) and the general public (see, for example, Campbell, 2014; Steinhauer and Strommarch, 2016) regarding the labelling of GM food products.

Currently, the policy options for labelling include voluntary labelling, mandatory labelling, and a ban on labeling (Huffman and McCluskey, 2014). Proponents of voluntary labelling claim that the 'need-to-know' perspective is sufficient. The 'need-to-know' perspective is concerned with information about potential allergens balanced with information overload on consumers and possible misinterpretation of scientific information where technology is judged to be safe (Qaim, 2009). A number of companies and initiatives already voluntarily provide labelling of food products regarding their avoidance of GMOs. Voluntary labelling does not require further regulatory measures. The costs associated with verification that the food product does or does not

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Statistics Canada, and in cases where Statistics Canada does not have relevant data, I have drawn on other sources including the ISSAA.

contain GMOs are only incurred by those consumers who choose to purchase the labelled product (Byrne et al., 2014).

Proponents of mandatory labeling claim the ‘right-to-know’ perspective is a first priority of consumer sovereignty. The ‘right-to-know’ perspective is part of the precautionary principle which imposes more ‘conservative’ safety standards with respect to certain kinds of risks (see CBAC, 2002, 15). Mandatory labelling would extend much further than voluntary labelling and would require, at a minimum, to identify all food products containing GMOs. Also, mandatory labelling would require further regulatory interventions including monitoring and enforcement. Effective monitoring and enforcement places greater burden on the production, transportation, marketing, and processing chain for crops. In cases where there is a mixing of GM with non-GM products a testing verification system is required to measure the concentration levels of GMOs and determine the maximum tolerance level in a product that still carries the non-GMO label. Given that tolerance levels differ from one country to another and between government regulatory agencies and the private sector the risks and costs of enforcement become very high. This affects the market for a particular commodity in the same way as an excise tax (Huffman and McCluskey, 2014; Sorqvist et al., 2016). For example, a recent study demonstrated that labelling would increase the cost of food to California households by $400 per annum (Zilberman et al., 2013).

The policy adopted in Canada and the US is voluntary labelling (see Government of Canada, 2016; USFDA, 2016). In Canada, Health Canada and the CFIA carry joint responsibility for federal food labelling policies under the *Food and Drugs Act*. There have been three major consultations since 1993 in Canada on the labelling of novel foods derived from genetic engineering. Based on these consultations, a set of guidelines were developed: mandatory labelling is required if there is a health or safety concern from allergens or a significant nutrient or compositional change; ensure labelling is understandable, truthful and not misleading; and permit voluntary positive or negative labelling on the condition that the claim is not misleading or deceptive and the claim itself is factual. In cases where the methods used to produce new plant varieties (such as hybridization or genetic engineering) do not present significant differences in nutritional or compositional properties or safety concerns compared to standard methods of traditional plant breeding, the method of development is not considered material information required to be disclosed in the labelling of foods. In 1999, the Canadian General Standards Board established a multi-stakeholder committee to undertake the development of the voluntary labelling standard. In 2004, the *Voluntary Labelling and Advertising of Foods That Are and Are Not Products of Genetic Engineering* was adopted as a national standard in Canada which provided guidelines for: model voluntary label declarations that are understandable and not misleading; positive and negative claims (e.g., 'products of genetic engineering' or 'not products of genetic engineering'); and labelling for single and multi-ingredient foods (CFIA, 2015b). Further research is required into the issue of labelling GM food products as GMOs become have become more pervasive in the food system.

Second, recent amendments to agricultural laws in Canada and the US that further strengthen federal agricultural legislation, support innovation in the agricultural industry, and enhance global market opportunities, facilitate the social reorganization of the agricultural industry (see, CFIA, 2015a; USDA, 2016). This has raised concerns about the increasing power that such laws render multinational agribusiness corporations and the possibility of bringing the agricultural biotechnology industry firmly within the purview of corporate control (Baines, 2013; CBAN, 2016c; Pechlaner, 2012). In the Canadian context, Bill C-18, the *Agricultural Growth Act* omnibus bill, was introduced in Parliament on 9 December 2013 and became law on 25 February 2015 (see CFIA, 2015). Among other things, Bill C-18 amends Canada's *Plant Breeders' Rights Act* (PBR) by: extending the duration of plant breeders' rights to 20 years for seeds; giving plant breeders power to authorize all reproduction, conditioning (cleaning and treating), importing and exporting of PBR protected varieties of seed or other propagating material; enabling end-point royalties on the whole crop following harvest instead of on purchased seed alone; and provide millions of dollars in additional revenues annually to multinational seed and agrochemical corporations that hold PBRs in Canada such as Monsanto, Bayer, Dow, DuPont, Cargill, Glencore International, Syngenta, Bunge, Limagrain, and BASF (NFU, 2016).

Bill C-18 has serious consequences for Canadian farmers: it converts farmers' right to save PBR protected seed into a government-given privilege which may be easily taken away; farmers are allowed to save and condition seeds, but not to stock them for subsequent years as farmers have done for millennia to safeguard against crop failure or disease; it enables government to pass regulations to remove class of farmers from the 'Farmers Privilege' and to restrict, prohibit or put conditions on the use of harvested material. In terms of the development of new varieties, restrictions on farmers' seed saving are not necessary for the development of new varieties. Also, if farmers are compelled to buy seed every year, seed companies can simply offer a mass market product and will have no incentive to develop varieties for specific local and regional conditions or avoid developing varieties that are not linked to other products (NFU, 2016). The development of new varieties by seed companies has undermined Canadian public breeding programs that have made immeasurable contributions to Canadian agriculture. Public breeding programs have worked with farming communities to develop varieties that are regionally adapted, less input-dependent, and can help farmers and the food system adapt to changing climates. Since 2005, the federal government has shut down or decreased the funding of a number of public breeding institutions in Canada (CBAN, 2015b). In summary, what we are witnessing is a further shift in the policies of the Canadian government from a supporter of national agriculture to a promoter of multinational agribusiness corporations as the primary economic agents. This is predicated on the global economic integration of the agricultural sector that is being facilitated by governments through regulation with agricultural biotechnology as a technical driver of production. Further study is required into these developments as livelihoods of farming communities and the food system are at stake. Emancipatory social transformation depends on popular democratic forces that challenge such outcomes.

Third, the present work on the development, adoption, and production of GM crops may be examined in light of the academic literature on the production of nature (see, for example, Burkett, 2015; Castree, 2014; Foster, 2000; Foster and Burkett, 2016; Smith, 2010). The development of biotechnology, not only in agriculture and the agro-food system, but also in industrial production, health care, and the environment, is the outcome of both natural-material conditions and social conditions. More specifically, this is reflected in the fact that the appropriation of germplasm and the subsequent protection of IP rights in agricultural biotechnology is not simply the result of scientific and legal practices, but an endogenously induced requirement, determined and intertwined with the material aspects of nature, (bio) technology, and social production in capitalist accumulation.

This raises questions about the interrelationship between nature, materialism, and science: “one that links social transformation with the transformation of the human relation with nature” (Foster, 2000, 1). The tendency in capitalism to degrade the natural conditions of human existence may be understood by drawing on Marx’s labour theory of value and various ecological perspectives that have followed (Burkett, 2015). This is “tied to the dynamics of capitalist production and the exploitative nature of work… Here, the market mediates the collective interaction and metabolism with nature that occurs with capitalist production” (Albo and Yap, 2016). GM crops may be viewed as not only material things but also as the embodiment of interacting relations (social, ecological, cultural, academic, and technical) (Yapa, 1993). Given the complexity of these issues, further investigation is required that explores the extent that the present work on the development, adoption, and production of GM crops exemplifies the research on the production of nature.

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Appendices

Appendix A: Informed Consent Form

Date:
Study Name:
Capitalism, Biotechnology, and Geographically Uneven Development
Researcher:
My name is Robert M. Bridi. I am a graduate student at York University and the principal investigator in this research project. My office is located at York University, 4700 Keele Street, Toronto, Ontario M3J 1P3 in the Ross Building RN406. My e-mail is rbridi@yorku.ca.
Purpose of the Research:
I am working on a research project that deals with issues related to the adoption of genetically modified crops. I want to request your participation in this research by answering some questions. I do not foresee any risks or benefits from your participation in this research. The approximate time for the interview is 30 to 45 minutes.

Your participation in the study is completely voluntary, and you may choose to stop participating at any time. Your decision to stop participating, or to refuse to answer any particular questions will not affect your relationship with the researcher, York University, or any other group associated with this project, now or in the future. In the event that you withdraw from the study, all associated data collected will be immediately destroyed.

All information you supply during the research will be held in confidence, and unless you specifically indicate your consent, your name will not appear in any report or publication of the research. I will be recording the interview, but if you prefer simply answering my questions without them being recorded, I will take handwritten notes. All the recordings, handwritten notes, and other interview materials will be safely stored in a locked facility at York University for three years after which it will be destroyed by shredding. Confidentiality will be provided to the fullest extent possible by law.

If you have any questions about the research in general or about your role in the study, please feel free to contact the Department of Geography either by telephone at 416-736-5107 or by e-mail at gradgeog@yorku.ca or Dr. Raju Das either by telephone at 416-736-5107, extension 22450 or by e-mail at rajudas@yorku.ca. This research has been reviewed and approved by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact Ms. Alison Collins-Mrakas, Manager, Office of Research Ethics, 309 York Lanes by telephone at 416-736-5914 or by e-mail at acollins@yorku.ca.
Legal Rights and Signatures:
I ________________________, consent to participate in Capitalism, Biotechnology, and Geographically Uneven Development conducted by Robert M. Bridi. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent.

Signature (participant): ________________________________ Date: ______________

Signature (principal investigator): ________________________ Date: ______________

Appendix B: Sample Interview Questions

Research Questions:	Data Sources:	Sample Interview Questions:
What are the economic implications of the production of GM crops for farmers in different localities?	Primary sources: farmers, and union members.	Name, address? How long have you been working in farming? How many of your family members work with you? Is this a first or second generation farm? How long have you been using GM seeds? Why did you switch from using traditional seeds to using GM seeds? Do you produce more with GM seeds than traditional seeds? Has your income increased or decreased after using GM seeds? Why do you think your income increased or decreased after using GM seeds? How many people do you support in your family? Is this your only source of income?
What is the role of state institutions and civil society at local and national scales in the	Primary sources: political parties, government officials,	Why have many Canadian state institutions promoted the use of GM crops?

development of biotechnology and GM crops?	company officials, NGOs, and intellectuals.	Why has GM canola been adopted at such a high rate? How has GM canola production fared for farmers? What measures have Canadian state institutions, both at the federal and provincial levels, taken for promoting GM canola? Does the government provide any incentive for people that adopt GM seeds? What role do Canadian state institutions play in increasing international collaboration in the GM sector through financial support or technological support? Why have many NGOs supported the adoption of GM technology in general and GM wheat in particular? Why has this resistance been successful in terms of blocking the adoption of GM wheat but bot GM canola?
How are constructed meanings about biotechnology, GM crops, progress, development, and economic growth serve to sustain and legitimate pro-GM and anti-GM discourses at local and national scales?	Primary sources: farmers, union members, political parties, government officials, company officials, NGOs, and intellectuals. Secondary sources: images, newspaper clippings, websites, and films.	How did you learn about GM seeds? What was your perception of GM seeds? What kind of information did you have about GM seeds? Where did you get information about GM seeds? Why did you adopt or not adopt GM seeds?

		Do you think adopting or not adopting GM seeds will benefit farmers? What advantages or disadvantages did you think adopting GM seeds would bring? Do you think adopting GM seeds is the way of the future of agriculture?